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Reclamation of Toxic Mine Waste Utilizing Sewage Sludge Contrary Creek Demonstration Project

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RECLAMATION OF TOXIC MINE WASTE
UTILIZING SEWAGE SLUDGE
CONTRARY CREEK DEMONSTRATION PROJECT

by

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Grant No. S-803801

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16. ABSTRACT Three abandoned pyrite mines in central Virginia that had been inactive since 1923 contained about 12 denuded ha and caused severe acid mine drainage (AMD) in a small stream known as Contrary Creek. The AMD included heavy metals and rendered the stream virtually void of aquatic life. The Virginia State Water Control Board (SWCB) was prompted to seek a solution to this problem when plans were announced in 1968 to construct a reservoir for a nuclear power plant downstream from Contrary Creek. Two of the mines comprising about 8 ha were reclaimed with an EPA demonstration grant with the SWCB contributing matching funds by in-kind services and the Soil Conservation Service providing technical assistance. Reclamation began in 1976 and included the use of sewage sludge as a soil conditioner. Severe droughts in 1976 and 1977 and the highly toxic nature of the mine wastes necessitated a continuing maintenance program to establish vegetation. By the fall of 1980 approximately 90 per cent of the reclaimed areas supported fair to good grass cover.

A comprehensive monitoring program has indicated little improvement in water quality since reclamation began. There appeared to be slight decreases in concentrations and loads of AMD in 1979 and 1980, but it is too early to tell if a remedial trend is beginning. Further improvement is expected as infiltration and AMD formation are reduced by development of a soil layer and vegetative cover. Biologic recovery has been negligible. The project has been extended until mid-1982 for continued maintenance.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes a demonstration project in which sewage sludge was utilized to reclaim toxic mine waste. As noted, the sludge, with the assistance of limestone and fertilizer, was successful in establishing vegetation on mine waste dumps that had been barren for over 50 years. In addition, these dumps were a major source of heavy metals to a nearby stream. Thus, a waste from one process, sewage treatment, is a valuable asset in the control of another environmental problem. The information contained in this report will be of interest to mine land reclamation specialists, regulatory agencies, and municipal waste treatment managers. For further information, contact the Industrial Environmental Research Laboratory.

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ABSTRACT

Three abandoned pyrite mines in Louisa County, Virginia that had been inactive since the early 1920's contained approximately 12 hectares virtually barren of any vegetation. The toxic nature of the mine waste resulted in the continuous leaching of acid and heavy metals into a small stream known as Contrary Creek rendering it essentially void of aquatic life. The severe acid mine drainage problem along this stream and associated fish kills downstream had been recognized for years. In 1968 with the announced plans to construct a reservoir as a source of cooling water for a nuclear power plant on the North Anna River into which Contrary Creek drained, the Virginia State Water Control Board was prompted to seek a solution to the problem.

Two of the mine sites comprising about 8 hectares were reclaimed with funds from a demonstration grant from the United States Environmental Protection Agency with the Virginia State Water Control Board contributing matching funds through in-kind services and the Soil Conservation Service providing technical assistance. The third mine site was reclaimed by a mining firm. Reclamation which began in 1976 consisted of regrading mine spoils, constructing diversions, applying soil amendments including wastewater sludge, limestone, and fertilizer and seeding. The purpose of the reclamation was to reduce the acid mine drainage into Contrary Creek and stabilize the mine waste to minimize erosion.

Severe droughts in 1976 and 1977 and the highly toxic nature of the mine waste has necessitated a continuing maintenance program to establish vegetation. Regular application of soil amendments and reseeding augmented by more normal rainfall in 1978 and 1979 resulted in an increased cover of vegetation and a pronounced decrease in erosion. Another dry summer in 1980 again hampered efforts to improve the vegetative cover, but overall loss of vegetation was minimal. By the fall of 1980 approximately 90 per cent of the reclaimed areas supported a fair to good cover of grass. Ky-31 fescue grass is the most successful planting.

Results of a comprehensive monitoring program still in progress have indicated little improvement in the water quality of Contrary Creek since reclamation began. There appeared to be slight decreases in concentrations and loads of acidity and some metals in water years 1979 and 1980, but it is too early to tell if an improving trend is beginning to emerge. Further improvement is expected as a result of the reduction in infiltration and acid mine drainage formation caused by the development of a soil layer and vegetative cover. The addition of sewage sludge and limestone should provide some in situ treatment of the acid mine drainage. Insufficient time has elapsed for these impacts to be seen in the stream system. Monitoring of the Contrary Creek arm of Lake Anna showed acid mine drainage to have a pronounced influence for a short distance out into the reservoir but apparently insignifi-

cant effect elsewhere in the lake. Biologic surveys have revealed negligible improvement in the biota in Contrary Creek since reclamation.

Average cost of reclamation including all maintenance for the two mine sites funded from the demonstration grant has been $14,518 per hectare.

In late 1980 the Environmental Protection Agency approved a request from the Virginia State Water Control Board to extend the project until mid-1982 to provide for continued maintenance as needed including application of soil amendments, seeding and erosion control.

This report covers all of the work completed in this project until the latter part of 1980.

CONTENTS

Foreword iii

Abstract iv

Figures ix

Tables xvi

Acknowledgments xx

1. Introduction 1

2. Conclusions and Recommendations 2

3. Background 4

    Location 4
    Climate 4
    Topography and drainage 6
    Geology 6
    Mining history 9
    Prereclamation conditions 11
    Early studies 13
    Chronology of events 19

4. Jurisdictional Framework 22

    Cognizant authority 22
    Water quality standards 22

5. Prereclamation Work 25

    Grant application 25
    Feasibility study 28
    Site easements 30
    Plans and specifications 31
    Bid advertising and award of contract 32
    Acquisition of wastewater sludge 32
    Monitoring program 33

CONTENTS (continued)

6. Reclamation Work - 1976 34

  Construction 34
  Application of sludge and other soil amendments 40
  Seeding 47
  Costs 47
  Results 49

7. Maintenance 52

  Spring 1977 52
  Fall 1977 56
  Spring 1978 60
  Fall 1978 63
  Spring 1979 66
  Fall 1979 71
  Spring - fall - 1980 75

8. Arminius Site Reclamation 76

9. Postreclamation Conditions 80

  Vegetative cover 80
  Erosion control 88
  Soil analyses 90
  Water quality 103
    Stream stations - concentration and load data 105
    Annual complete analyses 135
    Tributary stations 139
    pH and specific conductance transects - 1979 149
    Lake stations 149
    Summary of water quality data 170
  Biologic studies 179
    Summary of biologic studies 185

10. Special Studies 190

  Water quality study by University of Virginia 190
  Biologic study of Contrary Creek Arm of Lake Anna 192
  Revegetation studies at Arminius Site 192
  Metals uptake by vegetation - November 1978 192

11. Summary of Project Costs 196

References 199

Glossary 201

CONTENTS (continued)

Appendices

A. Generalized deed of easement 204
B. Analytical procedures 206
C. Metric conversion 208
D. Major sources of Acid and Heavy Metals which contribute to the Acid Mine Waters 209
E. Biological Survey of The Contrary Creek Arm of Lake Anna, Virginia 276
F. Experimental Studies at Arminius Tailings 311

FIGURES

No.		Page
1	Location of project	5
2	York River Basin drainage	8
3	Geologic map of Contrary Creek area	9
4	Generalized cross-section of mining operations at Sulphur Site	10
5	Tipple ruins at Sulphur Site	12
6	Portion of Sulphur Site prior to reclamation	12
7	Devastated stream banks of Contrary Creek at Sulphur Site	14
8	Erosional gully at Sulphur Site	14
9	Topography of Sulphur Site before reclamation	15
10	Old mine shaft entrance at Sulphur Site	16
11	Huge tailing pile at Sulphur Site	16
12	Topography of Boyd Smith Site before reclamation	18
13	Various work areas of Sulphur Site	35
14	Clearing and regrading of Boyd Smith Site - April 1976	36
15	Regrading of Large Area at Sulphur East - Spring 1976	36
16	Regrading of tailing pile at Sulphur West - Spring 1976	37
17	Regraded tailings at Sulphur West - Summer 1976	37
18	Construction work - Sulphur Site	38
19	Construction and seeding work - Boyd Smith Site - Summer 1976	39

FIGURES (continued)

No.		Page
20	Excavation of mine wastes from stream channel along Tailing Area at Sulphur West	41
21	Riprap section at mouth of Tr-2 at Sulphur East	41
22	Typical riprap section used in diversions	42
23	Typical riprap section used along stream banks	42
24	Dumping of sludge at Sulphur Site	44
25	Spreading sludge at Sulphur Site	44
26	Seeding work - Sulphur Site - Summer 1976	48
27	Seeding work - Sulphur Site - Spring 1977	53
28	Seeding work - Sulphur Site - Fall 1977	57
29	Preparation of seedbed with small disc	58
30	Seeding with a grain drill	58
31	Seeding work - Boyd Smith Site - Fall 1977	59
32	Seeding work - Sulphur Site - Spring 1978	62
33	Lime spreading by truck on Sulphur East	64
34	Sludge spread by earthmoving pan on Tr-1 of Sulphur West	64
35	Seeding work - Sulphur Site - Fall 1978	65
36	Seeding work - Sulphur Site - Spring 1979	68
37	Spreading lime by hand at Boyd Smith Site	70
38	Irrigation of Sulphur Site	70
39	Seeding work - Sulphur Site - Fall 1979	72
40	Seeding work - Boyd Smith Site - Fall 1979	73
41	Barren areas at Arminius East prior to reclamation	77
42	Mine tailings along Contrary Creek at Arminius West prior to reclamation	77

FIGURES (continued)

No.		Page
43	Arminius Site after reclamation - Fall 1978	78
44	Sulphur Site before reclamation	81
45	Sulphur Site in 1980	82
46	Boyd Smith Site before reclamation	83
47	Boyd Smith Site in 1980	83
48	Boyd Smith Site - Spring 1977	85
49	Same view as Figure 48 - Summer 1980	85
50	Large Area of Sulphur East - Spring 1977	86
51	Same view as Figure 50 - Summer 1980	86
52	View of Tailing Area of Sulphur West with Tipple Area of Sulphur East in foreground - Spring 1977	87
53	Same view as Figure 52 - Summer 1980	87
54	Vigorous growth of Ky-31 fescue on Large Area of Sulphur East - Summer 1979	89
55	Weeping lovegrass on Upstream Flat of Sulphur East-Fall 1979	89
56	Contrary Creek Monitoring Stations	104
57	pH versus time in calendar years at MS-2 compared with control station	118
58	pH versus time in calendar years at MS-3 compared with control station	118
59	pH versus time in calendar years at MS-4 compared with control station	119
60	pH versus time in calendar years at MS-5 compared with control station	119
61	Sulfate concentrations versus time in calendar years at MS-3 compared with control station	120
62	Sulfate concentrations versus time in calendar years at MS-4 compared with control station	120

FIGURES (continued)

No.		Page
63	Copper concentrations versus time in calendar years at MS-4 compared with control station	121
64	Copper concentrations versus time in calendar years at MS-5 compared with control station	121
65	Iron concentrations versus time in calendar years at MS-2 compared with control station	122
66	Iron concentrations versus time in calendar years at MS-4 compared with control station	122
67	Manganese concentrations versus time in calendar years at MS-3 compared with control station	123
68	Manganese concentrations versus time in calendar years at MS-4 compared with control station	123
69	Zinc concentrations versus time in calendar years at MS-2 compared with control station	124
70	Zinc concentrations versus time in calendar years at MS-3 compared with control station	124
71	Zinc concentrations versus time in calendar years at MS-4 compared with control station	125
72	Zinc concentrations versus time in calendar years at MS-5 compared with control station	125
73	Sulfate loads based on instantaneous flows versus time in calendar years at MS-3 compared with control station	126
74	Sulfate loads based on instantaneous flows versus time in calendar years at MS-5 compared with control station	126
75	Copper loads based on instantaneous flows versus time in calendar years at MS-4 compared with control station	127
76	Copper loads based on instantaneous flows versus time in calendar years at MS-5 compared with control station	127

FIGURES (continued)

No.		Page
77	Iron loads based on instantaneous flows versus time in calendar years at MS-4 compared with control station	128
78	Iron loads based on instantaneous flows versus time in calendar years at MS-5 compared with control station	128
79	Manganese loads based on instantaneous flows versus time in calendar years at MS-3 compared with control station	129
80	Manganese loads based on instantaneous flows versus time in calendar years at MS-4 compared with control station	129
81	Zinc loads based on instantaneous flows versus time in calendar years at MS-2 compared with control station	130
82	Zinc loads based on instantaneous flows versus time in calendar years at MS-3 compared with control station	130
83	Zinc loads based on instantaneous flows versus time in calendar years at MS-4 compared with control station	131
84	Zinc loads based on instantaneous flows versus time in calendar years at MS-5 compared with control station	131
85	Copper loads computed from instantaneous flows under base flow conditions versus time in calendar years at MS-4 compared with control station	133
86	Zinc loads computed from instantaneous flows under base flow conditions versus time in calendar years at MS-4 compared with control station	133
87	Iron loads computed from instantaneous flows under base flow conditions versus time in calendar years at MS-4 compared with control station	134
88	Manganese loads computed from instantaneous flows under base flow conditions versus time in calendar years at MS-4 compared with control station	134
89	Arminius Tributaries	142
90	Boyd Smith Tributaries	143

FIGURES (continued)

No.		Page
91	Sulphur Site Tributaries	144
92	pH and specific conductance transect from Lake Anna to above Arminius Site, July 30, 1979	154
93	Specific conductance transect along Contrary Creek at Boyd Smith Site, July 19, 1979	156
94	pH and specific conductance transect along Tr-8 at Boyd Smith Site, June 19, 1979	159
95	pH versus time in calendar years at surface level of SS-1	162
96	pH versus time in calendar years at bottom level of SS-1	162
97	Copper concentrations versus time in calendar years at surface level of SS-1	163
98	Copper concentrations versus time in calendar years at bottom level of SS-1	163
99	Zinc concentrations versus time in calendar years at surface level of SS-1	164
100	Zinc concentrations versus time in calendar years at bottom level of SS-1	164
101	Iron concentrations versus time in calendar years at surface level of SS-1	165
102	Iron concentrations versus time in calendar years at bottom level of SS-1	165
103	Iron concentrations versus time in calendar years at surface level of SS-2	168
104	Iron concentrations versus time in calendar years at bottom level of SS-2	168
105	Comparison of average copper concentrations by water year at affected stream stations	173
106	Comparison of average zinc concentrations by water year at affected stream stations	174

FIGURES (continued)

No.		Page
107	Comparison of average copper loads by water year at affected stream stations	175
108	Comparison of average zinc loads by water year at affected stream stations	176
109	Sources of acid mine drainage into Contrary Creek	177
110	Contrary Creek biological stations	180

TABLES

No.		Page
1	Average Monthly Precipitation at Louisa Weather Station-1941-1979	7
2	Monthly Precipitation at Louisa Weather Station - 1975 - 80	7
3	Monthly Precipitation at Contrary Creek Rain Gage - 1975-80	7
4	Chronology of Events	19
5	Budget by Cost Category Requested in Grant Application	27
6	Average Water Quality Analyses of Contrary Creek Prior to Reclamation	29
7	Lime and Fertilizer Application Rates - 1976	43
8	Sludge Application Rates - 1976	45
9	Average Concentrations of Constituents in Sludge Used at Contrary Creek in 1976 on Dry Weight Basis	46
10	Average Fertilizer Equivalents of Sludge Used at Contrary Creek in 1976 on Dry Weight Basis	46
11	Seed Species and Application Rates - 1976	47
12	Summary of Construction and Seeding Costs - 1976	50
13	Summary of Stone Costs - 1976	50
14	Fertilizer Application Rates - Spring 1977	54
15	Seeding - Spring 1977	54
16	Maintenance Costs - Spring 1977	55
17	Maintenance Costs - Fall 1977	60
18	Seeding - Spring 1978	61
19	Maintenance Costs - Spring 1978	61

TABLES (continued)

No.		Page
20	Maintenance Costs - Fall 1978	66
21	Seeding - Spring 1979	67
22	Maintenance Costs - Spring 1979	69
23	Lime and Fertilizer Application - Fall 1979	71
24	Seeding - Fall 1979	74
25	Maintenance Costs - Fall 1979	74
26	Maintenance Costs - 1980	75
27	Evaluation of Vegetative Cover in Late 1980	84
28	Soil Loss Equation Factors for Before and After Reclamation	91
29	Soil Data - SCS - pH-Nutrient Availability - 1975-76	92
30	Summary of Sludge Application	92
31	Summary of Lime Application Rates - 1976-80	93
32	Summary of Fertilizer Types and Application Rates - 1976-80	94
33	Soil Data - DCLS, pH - Lime Requirement by Titration Curve	96
34	Soil Data - DCLS, pH and Metals on Dry Weight Basis	97
35	Soil Data - WVU, pH, Lime Requirement, Nutrient Availability, Total Potential Acidity - March 1978	99
36	Soil Data - SCS, pH and Nutrient Availability in lbs/ac - March 1979	100
37	Soil Data - SCS, pH, Nutrient Availability - July 1979	101
38	Soil Data - SCS, pH, Nutrient Availability - October 1979	102
39	Soil Data - SCS, pH, Nutrient Availability in lbs/ac - 1980	103
40	Mean Annual Flows	106
41	Summary of Water Quality Data by Quarter at MS-1	107
42	Summary of Water Quality Data by Quarter at MS-2	109

TABLES (continued)

No.		Page
43	Summary of Water Quality Data by Quarter at MS-3	111
44	Summary of Water Quality Data by Quarter at MS-4	113
45	Average Concentrations by Quarter at MS-5	115
46	Load Values for High Flow Days	132
47	Water Quality Data - Additional Metals Included in Complete Analyses	136
48	Water Quality Data - Solids, Specific Conductance, Turbidity	137
49	Water Quality Data - Miscellaneous Parameters	138
50	Water Quality Data - Nutrients and Oxygen Demand Parameters	140
51	Monthly Composite Sludge Analyses on Dry Weight Basis-Blue Plains STP	141
52	Water Quality Data - Arminius Tributaries	145
53	Water Quality Data - Boyd Smith Tributaries	146
54	Water Quality Data - Sulphur East Tributaries	147
55	Water Quality Data - Sulphur West Tributaries	147
56	Water Quality Data - Miscellaneous Parameters-Contrary Creek Tributaries	148
57	pH and Specific Conductance Data for 6.6 Km Transect Along Contrary Creek, July 30, 1979	150
58	pH and Specific Conductance Data of Contrary Creek Tributaries, July 30, 1979	153
59	Specific Conductance Data for Transect Along Contrary Creek at Boyd Smith Site, July 19, 1979	155
60	pH and Specific Conductance Data for Transect Along Main Tributary (Tr-8) at Boyd Smith Site, June 19, 1979	157
61	SS-1 - Averages, Minimums, and Maximums of Water Quality Data, 1975-79	161

TABLES (continued)

No.		Page
62	SS-2 - Averages, Minimums, and Maximums of Water Quality Data, 1975-79	167
63	Comparison of Averages of All Depths at SS-1 and SS-2, 1975-79	169
64	Comparison of Solids and Specific Conductance at SS-1 and SS-2	169
65	Average Annual Concentrations by Water Year at Stream Stations	171
66	Average Annual Loads by Water Year at MS-1, MS-2, MS-3 and MS-4	172
67	Comparison of Loads at MS-4 and MS-5 on Basis of Instantaneous Flows August 18, 1977	178
68	Cursory Biologic Survey - October 1976	182
69	Cursory and Quantitative Biologic Survey - May 1979	186
70	Quantitative Biologic Study - April 1980	188
71	Species Mix and Per Cent Cover - Metals Uptake Study - November 1978	193
72	Metals Uptake of Vegetation	194
73	Summary of Federal Funds Expended thru FY 1980	197
74	Summary of SWCB Funds Expended FY 1976-1980	198

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Ronald D Hill, Environmental Protection Agency (EPA) Project Officer, has provided guidance throughout the duration of the project.

The Government of the District of Columbia was most cooperative in arranging the free delivery of wastewater sludge to the project site for use in reclamation.

Thomas V. Dagenhart, graduate student at University of Virginia (UVA), was most helpful with interpretation of water quality data. Chandler Mortimer, Consultant for Callahan Mining Corporation, willingly exchanged information and views on his work at the Arminius Site.

The Virginia Division of Consolidated Laboratory Services (DCLS) performed all analytical work on water and sludge and a major portion of the soil analyses. The Virginia Department of Highways and Transportation (VDH&T) provided aerial photo coverage of the project site.

The following Divisions of the SWCB contributed to the project: Valley Regional Office (VRO), overall management and coordination; Piedmont Regional Office (PRO), collection of water samples; Surface Water Investigations (SWI), installation and maintenance of flow gaging stations; Division of Ecological Studies (DES), biologic studies; Bureau of Administration and Finance (BAF), administration of grant funds, processing water quality data, and drafting work; Bureau of Enforcement (BE), execution of easements and input for Section 4 of this report.

SECTION 1

INTRODUCTION

This report describes a mine reclamation project performed with an EPA demonstration grant in Louisa County, Virginia. The objective of the project was to demonstrate methods by which acid mine drainage (AMD) including heavy metals could be abated from two abandoned pyrite mines which had been discharging for over 50 years into a stream known as Contrary Creek. This stream empties into Lake Anna, a reservoir completed for a nuclear power plant in 1972.

The project has been a cooperative effort between the Virginia State Water Control Board (SWCB), the Environmental Protection Agency (EPA), and the Soil Conservation Service (SCS). Overall management of the project has been by the Valley Regional Office (VRO) of the SWCB in Bridgewater, Virginia. Construction and seeding costs have been funded from an EPA demonstration grant with the SWCB providing matching funds through in-kind services consisting of project administration, monitoring, evaluation and report writing. The SCS has provided engineering services and technical assistance throughout the reclamation and maintenance phase of the project. A third inactive pyrite mine site along Contrary Creek is being reclaimed by a mining company.

A physical description of the project site, mining history, prereclamation conditions, and early studies are given in Section 3.

Section 4 presents the legal authority for undertaking the project with applicable SWCB regulations and water quality standards. Prereclamation work including grant application, feasibility study, site easements, plans and specifications, bid advertising, and award of contract are summarized in Section 5.

Section 6 describes the major reclamation phase in 1976, and Section 7 discusses the semi-annual maintenance that has been performed since the initial reclamation work. Both sections include detailed cost information. Section 8 gives a brief summary of the reclamation of the Arminius Site by Callahan Mining Corporation.

Postreclamation conditions in terms of vegetative cover, erosion control, soil analyses, water quality, and stream biota are covered in Section 9. The water quality discussion includes results of regular monitoring and supplemental studies.

Section 10 describes four special studies associated with the project, three of which appear in their entirety in the appendices. Section 11 summarizes all Federal and State costs through the end of FY 1980.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

(1) Fair to good vegetative cover has started to establish over about 90 per cent of the reclaimed mine sites, but severe drought during the first two years of work seriously hampered restoration efforts necessitating a continuing maintenance program. Some highly toxic areas along stream banks remain barren and other areas have a very thin soil cover supporting vegetation that is very vulnerable to drought.

(2) The use of digested wastewater sludge along with lime and fertilizer has been essential in promoting vegetation, and it is doubtful that a fraction of the success realized would have been possible without the sludge. No health hazards or ill effects to the environment are known to have resulted from the use of sludge in the project. Heavy application of lime has apparently resulted in a general increase in soil pH and there seems to be a close relationship between potash deficiency and the more difficult areas to vegetate.

(3) The most successful grass has been Ky-31 fescue with weeping lovegrass proving to be highly tolerant of hot dry weather. Legumes have not shown any appreciable success.

(4) Erosion has been reduced considerably with concomitant decrease in surface runoff of AMD.

(5) Analytical data from a comprehensive monitoring program show little improvement in water quality of Contrary Creek in terms of concentrations and loads since reclamation began, but continued development of plant cover should continue to reduce infiltration and eventually begin to abate leaching of acid and heavy metals. There is no way of predicting when significant improvement will occur.

(6) The principal causes of AMD are sudden flush-outs of oxidation products located in the stream bed and barren mine wastes by heavy rainstorms following extended dry periods, and continual seepage of mine waste leachate along the stream banks between storms.

(7) The Sulphur Site is the major contributor of AMD along Contrary Creek, but certain heavy metals appear peculiar to each mine site. Water quality steadily deteriorates downstream as Contrary Creek

passes each site, and the downstream reach between the Sulphur Site and Lake Anna where no reclamation has been done contributes significantly to the AMD.

(8) Biologic studies have shown meager improvement in aquatic life of Contrary Creek since reclamation began. Those stream reaches immediately below the mine sites remain highly toxic to all but the most tolerant organisms.

(9) The Contrary Creek arm of Lake Anna immediately below the mouth of the stream is definitely degraded by AMD, but the effect on the main body of the lake appears negligible.

(10) Average cost to date for reclamation including all maintenance has been $14,518 per hectare.

Recommendations:

(1) A project of this type will likely require several years of maintenance to assure permanent survival of vegetation. Regular inspections are necessary to determine maintenance needs including reseeding of problem areas and placement of erosion control measures. Soil tests should be conducted at least once annually to evaluate progress and to determine what soil additives might be needed. Fall seeding is generally more sucessful than spring seeding because of the risk of drought during the summer months.

(2) Whenever feasible wastewater sludge should be used in the reclamation of lands severely affected by mine wastes. The positive effects that sludge has in promoting vegetative growth on highly toxic areas have been well demonstrated in this project. Large urban areas that generate huge volumes of sludge and have problems obtaining disposal sites are the best sources to use. If work schedules permit and the terrain is favorable, it is desirable to have sludge dumped directly upon application areas rather than stockpiled nearby because of the extra handling involved.

(3) The ongoing water quality monitoring program in conjunction with this project should continue with stream stations sampled monthly for at least one year and then on a quarterly basis for a few more years. One monitoring station for measuring flows and collection of samples downstream from all mine sites should be maintained permanently. Biologic studies should continue at least biennially. It should be realized that the abatement of AMD of such a toxic nature as encountered in this project is by no means a short term process.

SECTION 3

BACKGROUND

LOCATION

The Contrary Creek Project is located in Louisa County, Virginia approximately 65 kilometers northwest of Richmond and 120 kilometers southwest of Washington, D. C. (Figure 1). The three reclaimed mine sites discussed in this report are located along Contrary Creek, a small stream which heads just north of the Town of Mineral and flows northeastward into Lake Anna, an impoundment constructed for a nuclear power plant. The mine sites are known as the Sulphur, Boyd Smith and Arminius.

Louisa County is predominantly rural with a population of about 17,000. The County has an area of 1,346 square kilometers, about 73 per cent of which is covered with secondary growth timber with pine and oak the dominant varieties. Lumbering is the primary industry as evidenced by the numerous sawmills and planing mills throughout the county. Of secondary importance is clothing manufacturing and diversified agriculture which includes production of small grains, corn, hay, livestock, and poultry.

The recent construction of Lake Anna which lies entirely within Louisa County and Spotsylvania County to the northeast has made the area a major recreational attraction. This reservoir with an area of 5,261 hectares and 322 kilometers of shoreline draws boaters and fishermen from throughout Virginia and surrounding states including the Washington, D.C. metropolitan area. The excellent sport fishing on Lake Anna is recognized nationally.

CLIMATE

Most of the following information was obtained from "Climatological Data" compiled by NOAA and reported by the Louisa Weather Station located approximately 4 kilometers west of the project area. As part of the monitoring program the SWCB installed a rain gage at the project site but a continuous record is not available due to malfunction and vandalism.

Humid summers and mild winters are characteristic of the area. The average growing season is 173 days from April 24 to October 14. Mean annual temperature is 13^{o}C and summertime highs range from 28^{o}C to 32^{o}C, but higher temperatures are not at all uncommon. Nighttime lows in the summer are usually between 15^{o}C and 20^{o}C. During the winter months daytime highs average 8^{o}C with nighttime lows around -3^{o}C. Freezing temperatures usually occur between 60 and 70 days a year and temperature usually falls below 0^{o}F at least once each winter.

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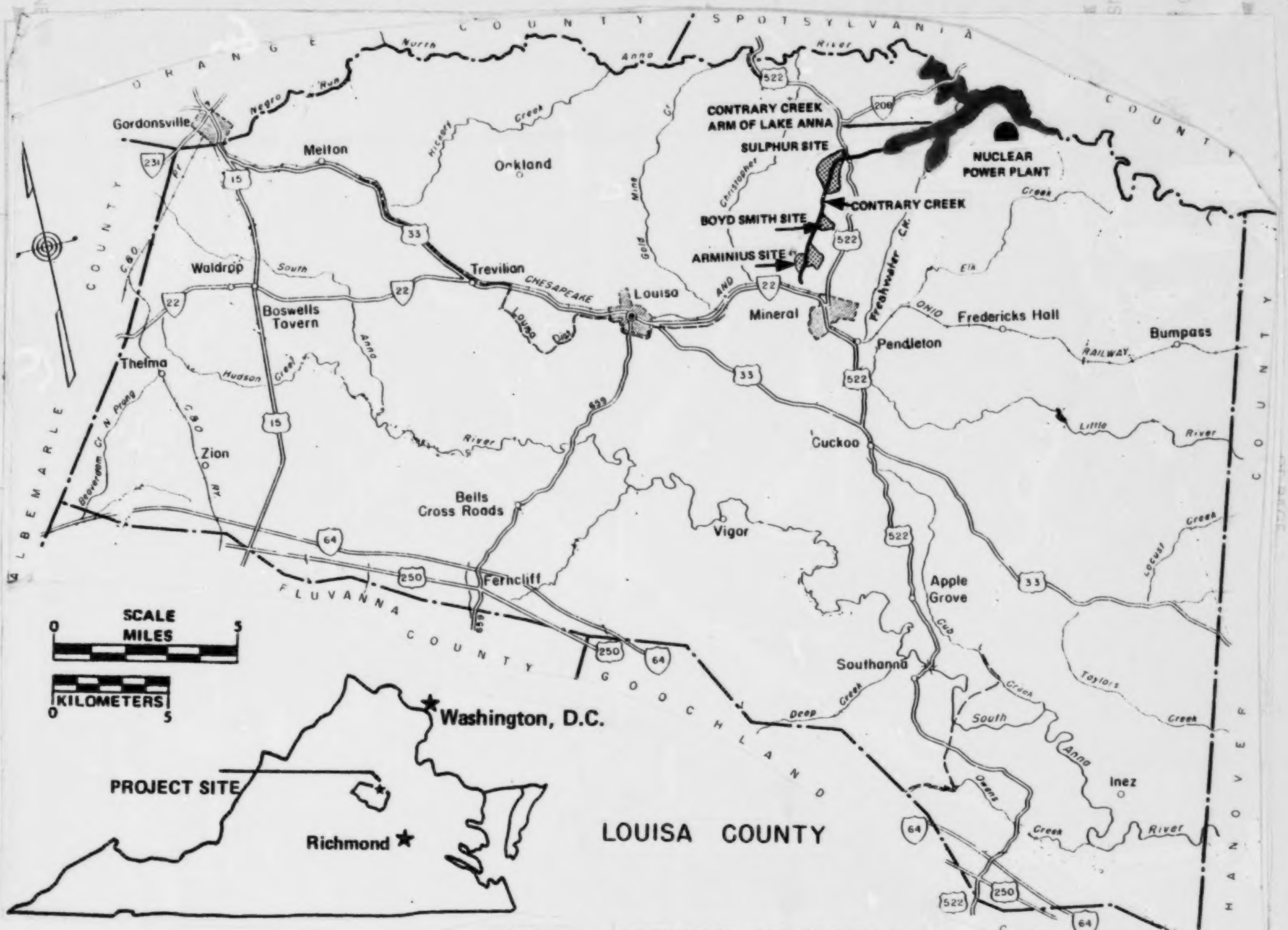

FIGURE 1. LOCATION OF PROJECT

Annual precipitation averages 109 centimeters and is usually fairly well distributed throughout the year. Total snowfall averages about 50 centimeters per year. Most of the precipitation falling on the project area results from storm systems moving northeastward from the southern Appalachians or eastward from the Ohio Valley. During the summer months thunderstorms and occasional hurricanes or other tropical disturbances account for a major portion of the rainfall. In 1969 Hurricane Camille dumped a record 28 centimeters of rain on the area within a 24-hour period. For the period of record from 1941 to 1979, July and August have been the months with the highest rainfall with February and April the driest months (Table 1). The driest year on record during this period was 1977 when only 78.2 centimeters of precipitation fell. Table 2 gives monthly precipitation records from the Louisa Station since the reclamation project started. Partial precipitation data from the rain gage installed in the project area are shown in Table 3.

TOPOGRAPHY AND DRAINAGE

The Contrary Creek Project is located in the Piedmont physiographic province which is characterized by a uniformly rolling surface with mild relief sloping gently southeastward from the Blue Ridge to the Coastal Plain. Elevation ranges from 90 to 120 meters above sea level in the project area. All of the major streams draining the Piedmont and Coastal Plain provinces flow in a southeastward direction. In the immediate project area the tributaries of the major streams flow northeastward in a well developed trellis pattern controlled by the geologic structure.

Contrary Creek lies within the York River Basin (Figure 2) and drains approximately 18 square kilometers in the north central part of Louisa County. Before the construction of Lake Anna, Contrary Creek flowed into Freshwater Creek which in turn emptied into the North Anna River which drains a major portion of the York River Basin. The length of Contrary Creek is now approximately 8 kilometers and average flow at the mouth of the stream is 207 liters per second (7.3 cfs).

GEOLOGY

The Piedmont province is mostly underlain by a complex of igneous and metamorphic rocks of Precambrian age consisting chiefly of granites, schists, and gneisses occurring in northeastward trending belts generally paralleling the Appalachian Mountain Range. In most places a thick layer of residual soil covers the deeply weathered bedrock which contains a wide variety of minerals. The pyrite mines along Contrary Creek were developed in a four-mile wide belt of crystalline schists striking N40E and dipping 65°SE (Figure 3). The extensively metamorphosed schists intruded by pegmatities, quartz veins, and diabase dikes have probably been altered from sedimentary rocks. This belt of highly mineralized rocks occurring between two masses of granitic rocks is part of the so-called pyrite-gold belt of Virginia. In addition to pyrite a vast assemblage of minerals including garnet, hornblende, biotite, and magnetite occur in this region attracting many rockhounds.

TABLE 1. AVERAGE MONTHLY PRECIPITATION AT LOUISA WEATHER STATION - 1941 - 1979 (cm)[a]

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
7.8	7.3	9.7	7.5	9.2	9.6	11.7	11.6	8.4	8.8	8.0	9.2	108.8

TABLE 2. MONTHLY PRECIPITATION AT LOUISA WEATHER STATION 1975 - 1980 (cm)[a]

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1975	8.4	5.9	16.4	4.6	8.5	26.7	20.2	7.8	24.0	4.8	5.1	9.9	142.3
1976	9.3	3.9	7.2	4.1	8.2	11.6	6.8	10.9	10.7	22.3	3.7	4.8	103.4
1977	4.3	1.0	6.2	4.6	3.6	3.7	5.2	5.3	5.2	11.5	14.7	12.6	77.9
1978	21.7	0.7	10.3	9.3	12.1	14.6	13.7	21.0	6.0	2.9	6.6	9.2	128.1
1979	14.1	13.0	9.6	8.5	8.7	10.0	2.3	12.7	19.7	13.9	8.2	2.1	122.8
1980	11.5	2.7	9.7	5.3	7.9	1.4	8.4	11.0	2.2				

TABLE 3. MONTHLY PRECIPITATION AT CONTRARY CREEK RAIN GAGE - 1976 - 1980 (cm)[a]

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1976[b]					9.4		9.3	12.7	8.3	20.4	3.3	5.1
1977	3.8	1.0	4.8	3.4	3.2	3.0	6.2	5.1	9.8	12.7		16.6
1978				8.9	10.2	8.0	6.5	11.3				
1979					7.2	9.6	1.9	11.8	20.9	7.5	6.0	1.3
1980	11.7	1.9	10.9	4.7	8.6	0.3	7.7	17.3	2.2			

[a] To convert centimeters to inches multiply by 0.394.
[b] No records are available where no measurement appears.

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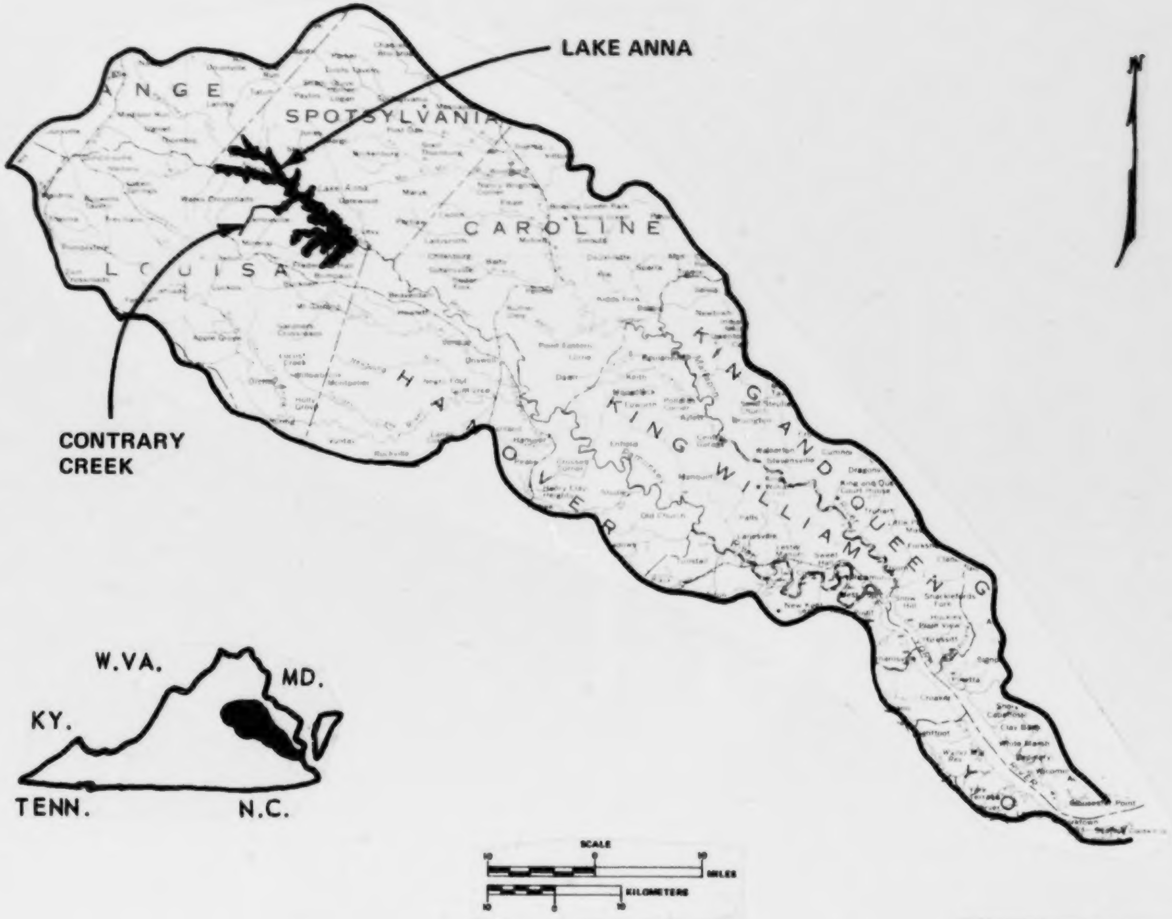

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FIGURE 2. YORK RIVER BASIN DRAINAGE

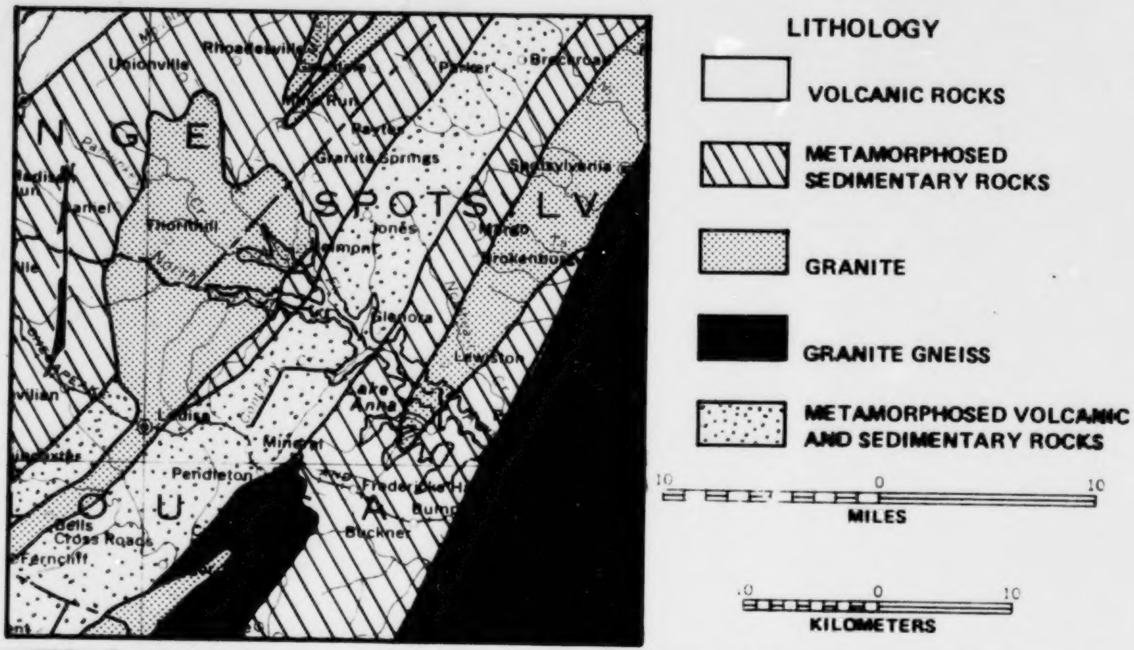

FIG. 3 GEOLOGIC MAP OF CONTRARY CREEK AREA (MODIFIED FROM GEOLOGIC MAP OF VIRGINIA, 1963, VIRGINIA DIVISION OF MINERAL RESOURCES)

Massive lenses of pyrite ore conforming to the regional strike occur within the enclosing schistose rocks. The ore bodies are usually 10 to 15 meters thick and up to 200 meters in length. Where discontinuous, the pyritic lenses are often connected by stringers of ore. The ore deposits are the typical gossan type with the pyrite weathered to iron oxides forming the caprock at the surface, underlain by a zone of secondary enrichment which is in turn underlain by the unweathered pyrite ore (Figure 4). Generally the contact between the ore bodies and the schistose rocks is sharp but some grading into the country rock occurs.

MINING HISTORY

The earliest mining along Contrary Creek began in 1834 when gossan iron ore pits were excavated at the Arminius Site. Gossan was mined from open pits at all three mine sites until about 1877 and was used to supply furnaces at the Arminius and Sulphur Sites. These old pits as much as 20 meters deep and extending along the strike of the ore bodies can still be seen, but they are not believed to be a significant factor in the pollution problem along Contrary Creek. Copper was mined on a small scale from the enriched mineralized zone beneath the gossan deposits concurrently with the iron mining.

Around 1880 the rich pyrite deposits beneath the gossan pits along Contrary Creek began to attract attention when it was determined that it was more profitable to manufacture sulfuric acid from pyrite rather than from brimstone. The fact that the pyrite deposits were so near the surface also favored development. Deep shaft mining for pyrite began at all three mine sites during the

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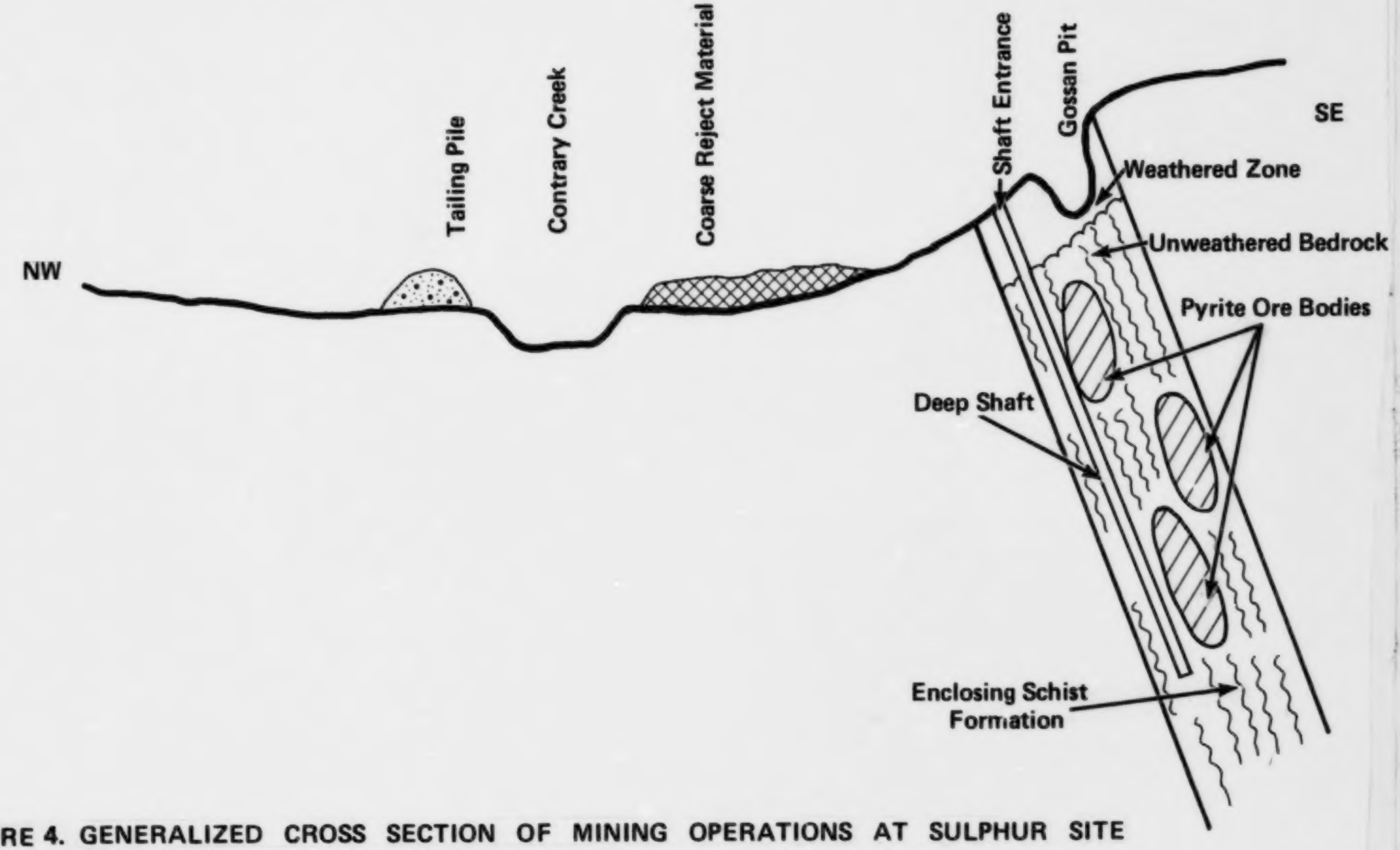

FIGURE 4. GENERALIZED CROSS SECTION OF MINING OPERATIONS AT SULPHUR SITE (NOT TO SCALE)

1880's and continued until 1923. Portions of the old tipple structures are still standing at both the Boyd Smith and Sulphur Sites (Figure 5). A total of 8 shafts are believed to have been developed at the Sulphur Site, and 3 were constructed at the Boyd Smith Site. The deepest shaft at the Sulphur Site was 220 meters but none of the shafts at the Boyd Smith Site were deeper than 90 meters. Some shafts at the Arminius Site reportedly exceeded 300 meters in depth. All of the shafts were on the east side of Contrary Creek.

The shafts were inclined in the general direction of dip of the bedrock, that is, southeastward toward present Route 522 (Figure 4). After the shafts were sunk, levels were run out at various elevations in both directions along the strike paralleling Contrary Creek. The lateral extent of the levels is unknown but surface evidence indicates that operations extended well beyond the immediate vicinity of the shafts. Ore was broken by overhand stoping, conveyed by mule-drawn carts to shafts, and brought to the surface by skips where it was washed and crushed to various sizes for marketing by rail. The coarse reject material consisting mainly of schists was dumped near the shaft entrances on the east side of the Creek at all three mine sites. At the Sulphur Site the fine tailings were conveyed across the Creek leaving huge spoil piles on the west side (Figure 6). It was this indiscriminate dumping of mine waste that resulted in the serious pollution problem along Contrary Creek.

The real heyday of the mining era was between 1910 and 1920 when about 2,000 men were employed at the three mine sites. At this time Virginia was the leading pyrite producer in the U.S. Over 6 million tons of pyrite ore were reportedly produced at all three mine sites during their operating period.

Pyrite mining in Louisa County terminated rather abruptly when the less expensive method of producing sulfur by the Frasch process was developed in the Gulf Coastal Plain. The mines along Contrary Creek could no longer operate on a competitive basis and by 1923 all three mines had closed and have not operated since.

Over the past 30 years tests have been conducted for various minerals at the Arminius and Boyd Smith Sites but results have not warranted any new production of ore. During the mid-1970's Callahan Mining Corporation formed a partnership with New Jersey Zinc Company, owners of the Arminius Site, and did some exploratory work near the project area on the east side of Route 522. The mining company considered using the Arminius Site for milling operations in the event a decision was made to go into production. The plan has not materialized to date.

PRERECLAMATION CONDITIONS

Over 50 years after the mines along Contrary Creek had been closed, approximately 12 hectares of land remained barren of vegetation as a result of the toxic character of the spoil at the three mine sites (Figure 7). A few scattered patches of Virginia pine had been able to establish over some of the less toxic areas but most of the waste areas supported no vegetation at all. Some places resembled pictures of the lunar surface. Erosion had cut deep gullies

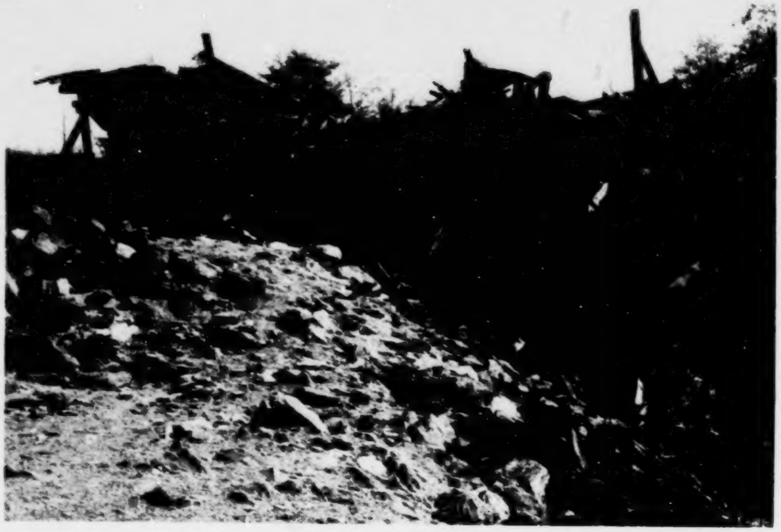

Figure 5. Tipple ruins at Sulphur Site.

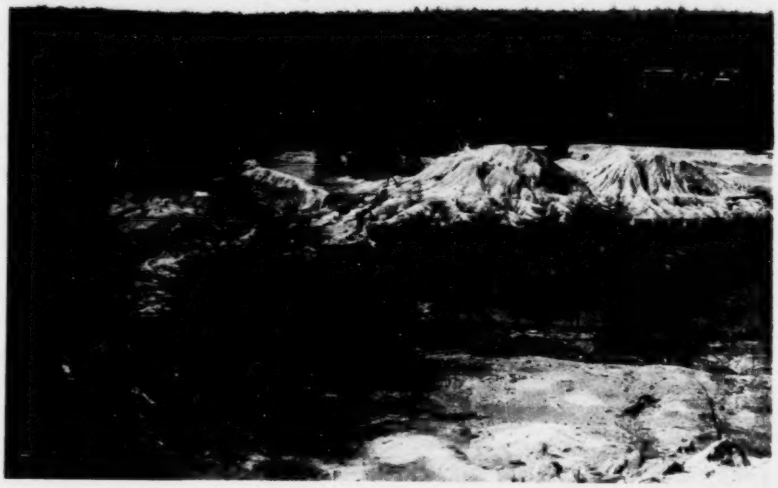

Figure 6. Portion of Sulphur Site prior to reclamation.

through and around the tailing piles (Figure 8) and vast quantities of pyritic material had been washed into the main stream channel and its tributaries. Much of this material was carried downstream below the mine sites toward what is now Lake Anna.

The Sulphur Site was by far the worst of the three mine sites. Approximately 6 hectares of the Sulphur were covered with mine wastes drastically altering the natural contours. Figure 9 depicts topography of the Sulphur Site prior to reclamation. Four of the old shaft entrances (Figure 10) were still evident and a deep pool of highly acidic water filled a depression reportedly caused by a cave-in. Huge tailing piles retained by cribbing on the west bank of Contrary Creek rose about 9 meters above the stream bed (Figure 11). On the east side of the Sulphur most of the wastes consisted of the coarse reject material which fanned out from the old shaft entrances. All of this reject material was highly mineralized and consisted of boulders up to 60 centimeters in diameter.

Conditions at the Boyd Smith Site were considerably less severe. About 2 hectares were covered with 1 to 2 meters of tailings spreading out from the shaft entrances toward Contrary Creek, but the natural topography was not significantly disturbed. There was no profuse amount of pyritic material immediately adjacent to nor in Contrary Creek, but a tributary traversing the waste area was badly clogged with tailings. A small amount of AMD still seeps directly from an old shaft here, but it apparently contributes insignificantly to the overall AMD problem.

The AMD problem along Contrary Creek and its detrimental effect upon aquatic life in the North Anna River had been recognized for some time. Two fish kills investigated in 1970 by the Virginia State Water Control Board in the North Anna River were attributed to the AMD problem, and even to the casual observer it was apparent that Contrary Creek had been rendered virtually sterile by the continuous leaching of AMD into the stream.

Most of the AMD entering Contrary Creek apparently resulted from leaching of sulfuric acid and metallic salts from under the massive tailing piles and from surface runoff during and immediately after periods of heavy rainfall. As stated above some seepage emanates directly from the old shafts during wet periods, and there was and still is continual slow seepage from under the stream banks in the more severe areas.

EARLY STUDIES

During the mid-1950's landowners affected by the mine waste areas along Contrary Creek sought help in alleviating the problem from the SCS through the Thomas Jefferson Soil and Water Conservation District. Between 1957 and 1968 the SCS conducted a series of soil analyses from the mine sites which revealed persistent low pH's and deficient levels of calcium, plant nutrients and organic matter. Using lime, fertilizer and mulch, the SCS tested various types of grasses at the Boyd Smith and Sulphur Sites in the early 1960's. Of the grasses tested only the Ky-31 fescue showed any degree of success. Con-

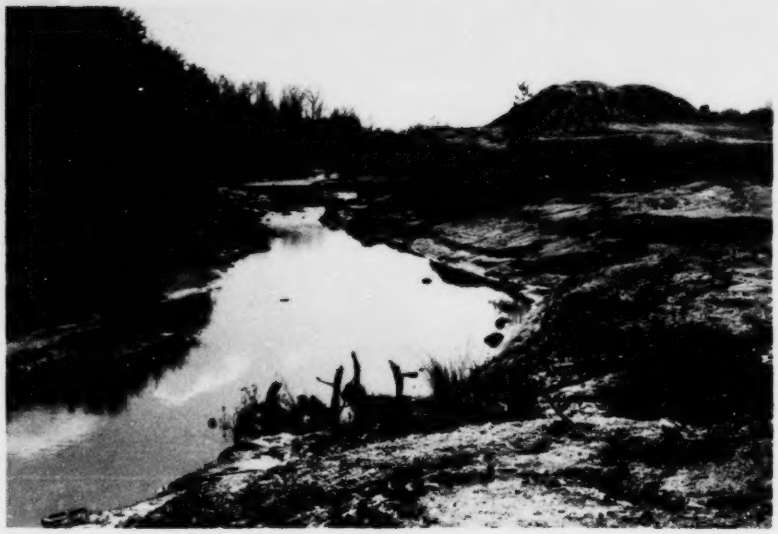

Figure 7. Devastated stream banks of Contrary Creek at Sulphur Site.

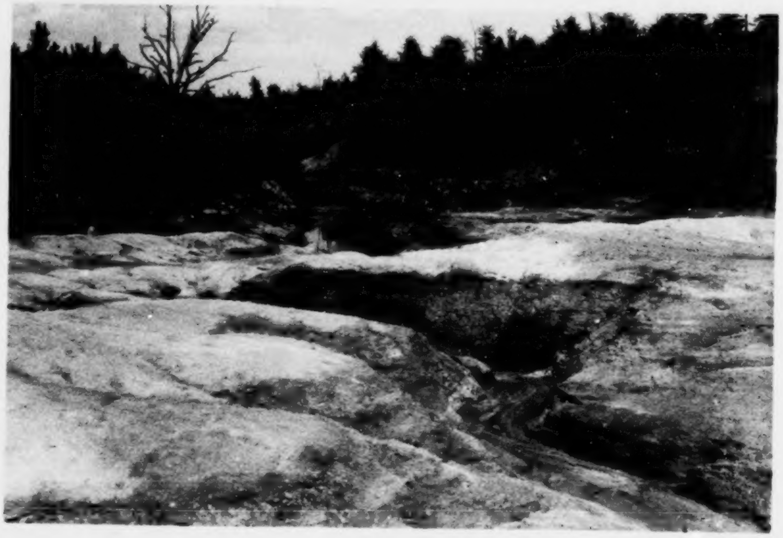

Figure 8. Erosional gully at Sulphur Site.

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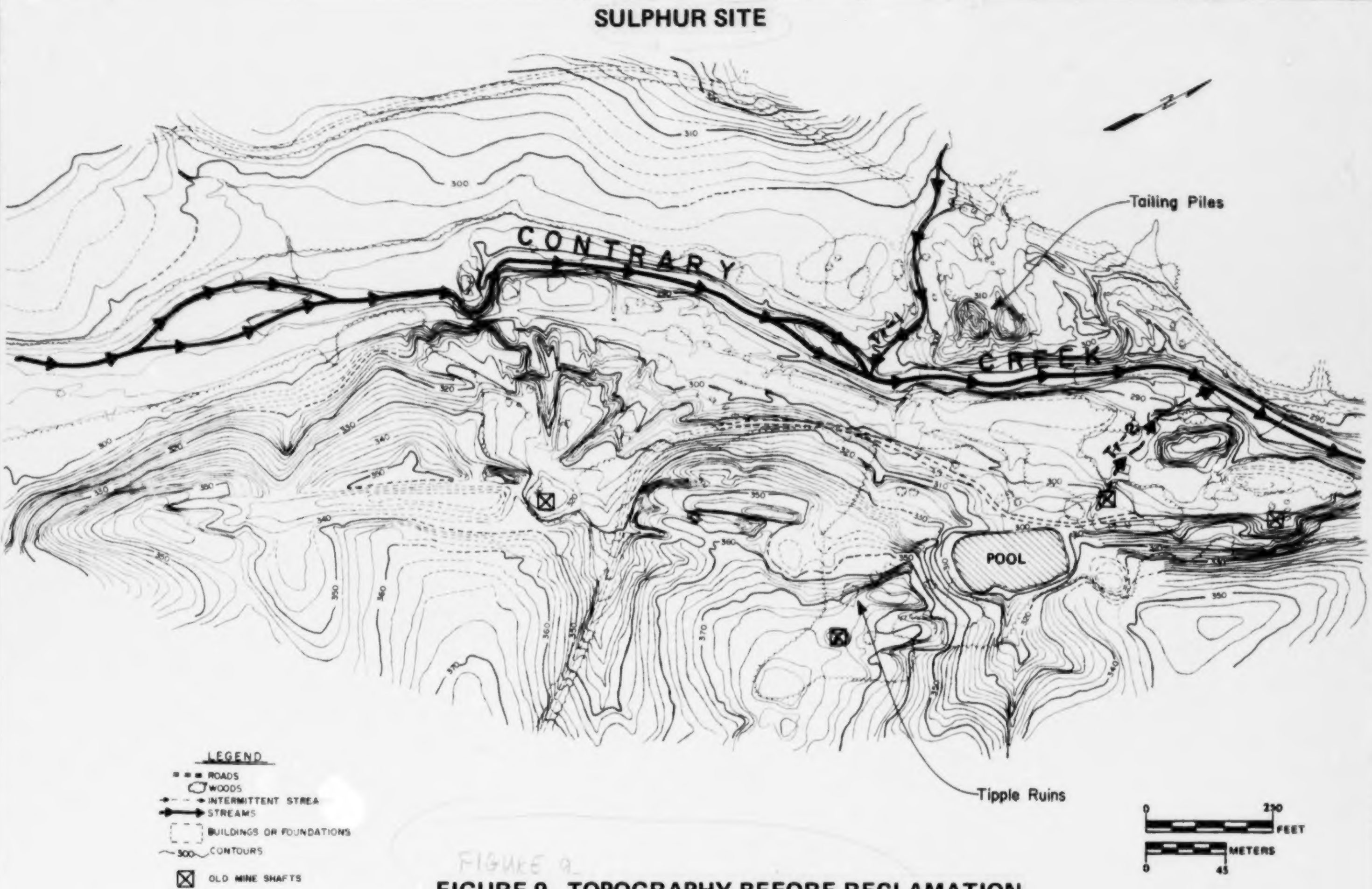

FIGURE 9

FIGURE 9. TOPOGRAPHY BEFORE RECLAMATION

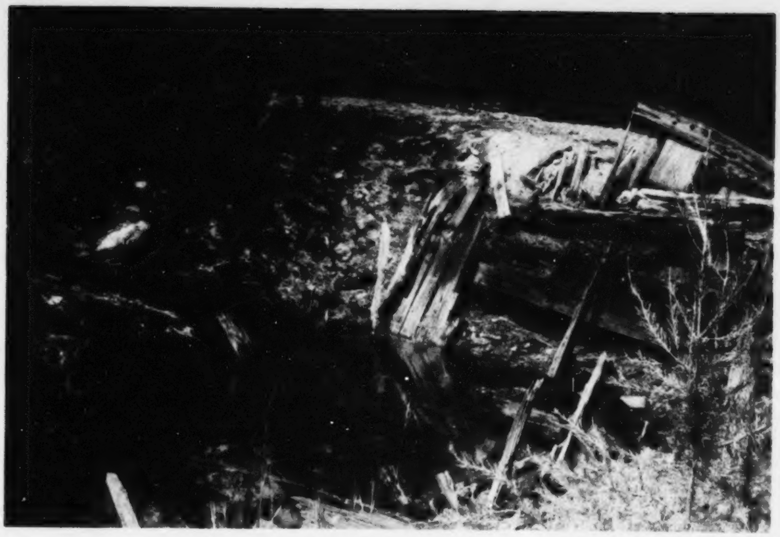

Figure 10. Old mine shaft entrance at Sulphur Site.

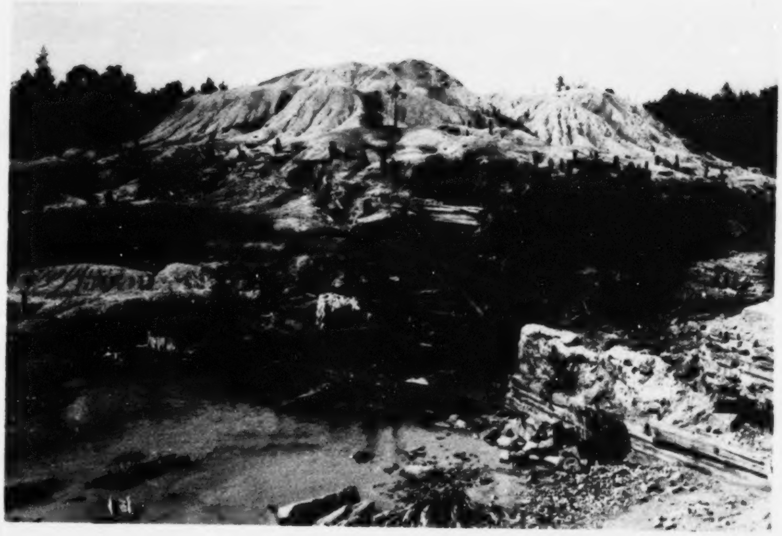

Figure 11. Huge tailing pile at Sulphur Site.

current with the SCS work the Virginia Forest Service planted several test plots of trees and shrubs at the Boyd Smith Site (Figure 12), but only Virginia pine and black alder had good survival rates. Some of these trees were still growing at the Boyd Smith Site in 1980.

When the Virginia Electric Power Company (VEPCO) decided to build a nuclear power plant on the North Anna River, the problem along Contrary Creek began to cause more concern. It was feared that with the construction of an impoundment there would be danger of a buildup of contaminants with the continual influx of AMD into the lake. A study conducted by the Commission of Game and Inland Fisheries (CGIF) in August 1968 stated that aquatic life was virtually non-existent in Contrary Creek and that fish populations in the North Anna River were being affected. In October 1971 the Virginia Soil and Water Conservation Commission held a meeting with interested governmental agencies and VEPCO to coordinate an evaluation of previous studies and make future recommendations on the Contrary Creek problem. Attending this meeting were representatives from the SWCB, CGIF, Commission of Outdoor Recreation, Division of Mineral Resources, Division of State Planning and Community Affairs, SCS and the Biology Department of Virginia Polytechnic Institute and State University (VPI&SU). It was decided at this time that the best course of action would be to seek an EPA grant which should be used to demonstrate the feasibility of correcting the AMD problem. More data would be required before applying for a grant and it was agreed that each representative agency would provide pertinent data. Since the SWCB is the State's primary water quality and resource agency, it was determined that that agency would be responsible for seeking a solution to the problem.

The SWCB conducted the first chemical survey of Contrary Creek in November 1971. Water samples were collected above and below suspected discharges at all three mine sites along Contrary Creek and analyzed for pH and heavy metals. The analyses revealed that there were indeed numerous sources of heavy metals and acid in high concentrations at all three mine sites. The metals that were found to be present in excessive amounts were iron, copper, zinc, manganese and lead. It was also very evident that the water quality deteriorated steadily downstream as the stream passed each mine site. Some of the samples taken directly from spoilbank seepage revealed extremely high concentrations of metals and acid.

A pre-impoundment biologic study completed by Dr. George M. Simmons, Jr. of VPI&SU in 1972 showed a 65 per cent reduction in the number of fish species and a 50 to 60 per cent reduction in the standing fauna crop in the North Anna River below the mouth of Contrary Creek. The study further showed that the North Anna River didn't fully recover biologically for at least 22 kilometers downstream from the confluence of Contrary Creek. Another study by Dr. Simmons showed a dramatic decrease in aquatic life in Contrary Creek itself below the mine areas. Dr. Simmons concluded from the observation of fauna in the tributaries that the potential for biotic recovery was very good provided the water quality could be restored in Contrary Creek. However, he predicted that if the leaching of AMD continued, the concentration of heavy metals in Lake Anna could cause fish kills within 5 to 10 years and that a sudden flush-out of heavy metals could result in fish kills even sooner.

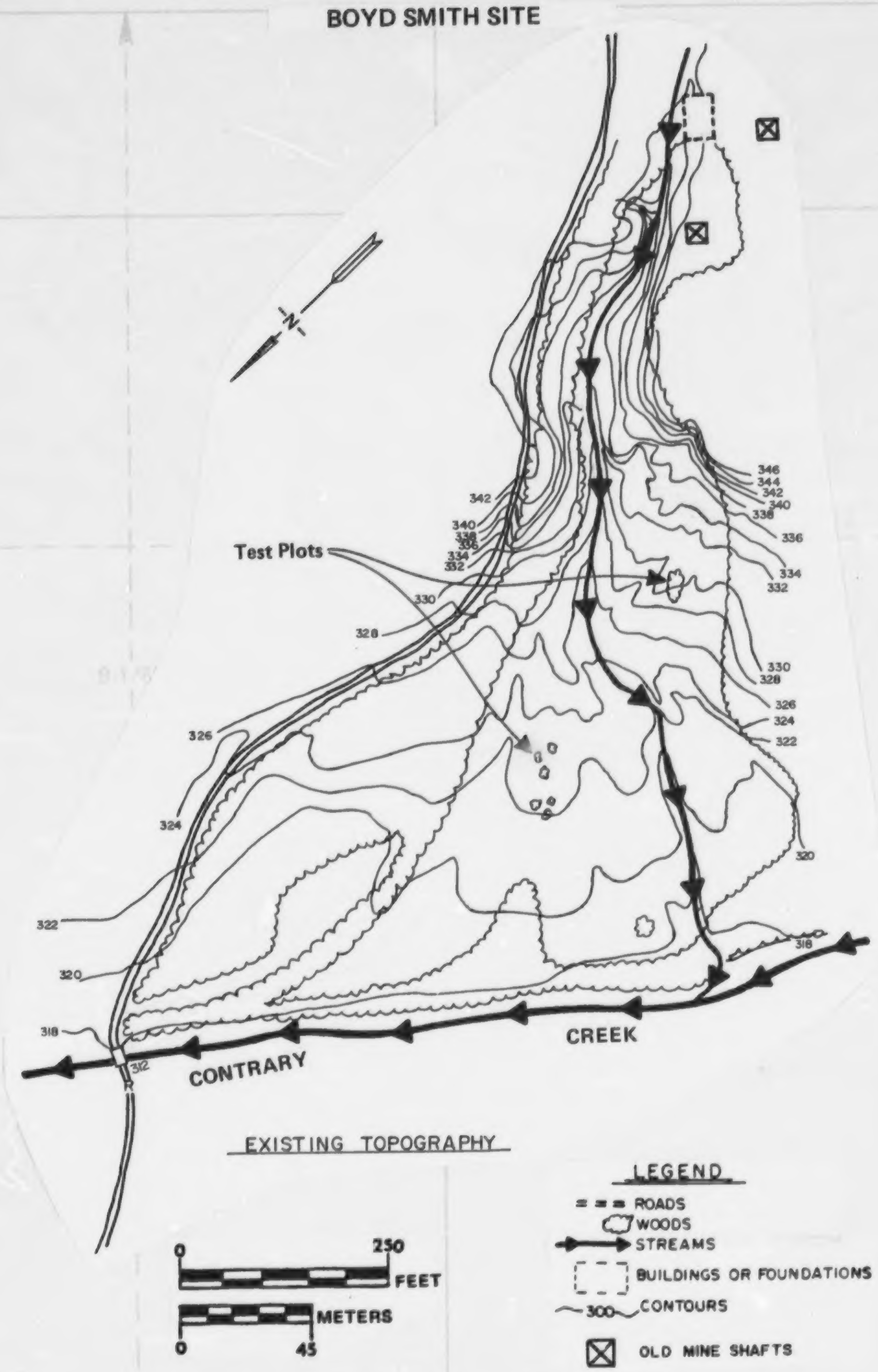

FIGURE 12. TOPOGRAPHY BEFORE RECLAMATION

The Environmental Impact Statement published in 1973 by the U.S. Atomic Energy Commission on the proposed North Anna power station stated that AMD from Contrary Creek could have serious effects upon the aquatic life in the impoundment and that heavy metal concentrations in fish flesh could render it unfit for human consumption. The Lake Anna Reservoir was completed in January 1972 and primarily due to Hurricane Agnes in June, the reservoir was filled by December 1972.

CHRONOLOGY OF EVENTS

Major events for the project prior to, during and after reclamation are itemized chronologically in Table 4.

TABLE 4. CHRONOLOGY OF EVENTS

1957 - 1968:	Soil Conservation Service and Virginia Division of Forestry conducted soil analyses at mine sites and planted test plots.
April 1968:	Virginia Electric Power Company announced plans to build a nuclear power plant on North Anna River.
May 1968:	Various State and Federal agencies including SWCB began making assessment of AMD problem and making recommendations for a solution.
August 1968:	Virginia Commission of Game and Inland Fisheries conducted study.
October 1971:	Various agencies involved decided to explore possibility of obtaining an EPA demonstration grant with the SWCB assuming responsibility for the project.
November 1971:	SWCB conducted first water quality study of Contrary Creek.
1972:	Pre-impoundment biologic studies conducted by VPI&SU. Lake Anna reservoir completed.
September 1973:	SWCB formally decided to apply for EPA grant.
December 1973:	Gannett Fleming Corddry and Carpenter retained to conduct feasibility study.
February 1974:	Callahan Mining Corporation contacted SWCB about their interest in Arminius Site.
March 1974:	Grant application submitted to EPA.

(continued)

TABLE 4. (continued).

April 1974:	Grant application rejected.
June 1974:	EPA advised that grant application would be reconsidered provided costs could be reduced.
	SWCB requested technical assistance from SCS.
November 1974:	Scope of project reduced.
	SCS agreed to provide engineering services.
	Callahan Mining Corporation assumed responsibility for reclamation of Arminius Site.
January 1975:	Final text of feasibility study completed.
February 1975:	Revised grant application submitted to EPA.
June 1975:	EPA grant awarded.
July 1975:	Demonstration project officially began.
August 1975:	Deeds of easement with property owners completed.
October 1975:	SCS prepared plans and specifications for bid package.
	Monitoring program began.
December 1975:	Bid advertisement.
January 1976:	Site showing to prospective bidders.
February 1976:	Bid opening.
March 1976:	Construction and seeding contracts awarded.
	District of Columbia agreed to deliver wastewater sludge for use in reclamation at no cost.
April 1976:	Major reclamation phase began.
July 1976:	All construction and seeding work at Boyd Smith and Sulphur Sites completed.
October 1976:	Callahan Mining Corporation began reclamation of Arminius Site.
1977:	Spring and fall maintenance.

(continued)

TABLE 4. (continued)

1977:	Special water quality study by University of Virginia began.
1978:	Spring and fall maintenance.
	Grant period extended for one year.
1979:	Spring and fall maintenance.
	Grant period again extended for one year.
	Special water quality study completed.
1980:	Spring and fall maintenance.
	Grant period extended until 1982.

SECTION 4

JURISDICTIONAL FRAMEWORK

Under the provisions of Section 107 of PL 92-500 the Virginia State Water Control Board applied for and was awarded a demonstration grant by the United States Environmental Protection Agency to be used in reclaiming two of the abandoned mine sites along Contrary Creek. The Commonwealth of Virginia had the responsibility of managing and administering the project including securing of easements, contracting reclamation work, performing all monitoring work, and preparing reports. The Soil Conservation Service has provided engineering and technical assistance.

COGNIZANT AUTHORITY

The Virginia State Water Control Board has the authority under Chapter 3.1, State Water Control Law, of the Code of Virginia (1950, as amended) to protect and safeguard the waters of the State, prevent any increase of pollution and reduce existing pollution in order to permit all reasonable public uses and provide for the health, safety and welfare of the citizens of the Commonwealth.

Section 62.1-44.15(4) of the Code authorizes the SWCB to conduct or have conducted scientific experiments, investigations, studies and research to discover methods for maintaining water quality consistent with the purposes of the Chapter. This demonstration project has been performed under the authority of this Section of the Code.

WATER QUALITY STANDARDS

Contrary Creek falls within Section 3 of the York River Basin and is designated by the State Water Control Board as a Class III stream. This classification refers to free flowing streams (Coastal Zone and Piedmont Zone).

The following specific standards apply to all Class III streams:

Dissolved Oxygen	(mg/1)
Minimum	4.0
Daily average	5.0
pH	6.0-8.5

Temperature °C

Maximum rise above natural*	3
Maximum	32
Maximum hourly change**	2

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* Natural temperature is that temperature of a body of water due solely to natural conditions without the influence of any point-source discharge. Any rise above natural temperature allowed by the SWCB shall be determined on a case-by-case basis and should not exceed 3°C except in the case of Class VI waters where it shall not exceed 1°C.

** The maximum hourly temperature change of 2°C is to apply beyond the boundary zones and does not apply to temperatures caused by natural conditions.

In addition, the following general standards are applicable to Contrary Creek:

> "In all surface waters, except those where leased private or public shellfish beds are present, the fecal coliform bacteria shall not exceed a log mean of 200 fecal coliform bacteria per 100 ml of water with not more than 10 per cent of the total samples during any 30-day period exceeding 400 per 100 ml."
>
> " All state waters shall be maintained at such quality as will permit all reasonable beneficial uses and will support the propagation and growth of all aquatic life, including game fish, which might reasonably be expected to inhabit them."
>
> " All State waters shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with reasonable, beneficial uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life."

Although neither Contrary Creek nor Lake Anna constitute a public water supply at this time, the water quality standards adopted by the SWCB for application to specific drinking water sources are used as a reference for discussing the water quality monitoring in this report.

The following standards excerpted from "Water Quality Standards," Virginia State Water Control Board, Richmond, Virginia, 1980 apply at the water intake and for a distance upstream. This distance from the intake is to be determined on a case-by-case basis by the SWCB considering upstream wastewater volume, receiving stream volume and other appropriate physical, chemical and biological factors. The standards will apply to both the water supply stream and its tributaries within the designated distance. (In case of existing water supplies, the standards will apply at the intake point until further change is made.)

CONSTITUENT	CONCENTRATION (MG/L)
Arsenic	0.05
Cadmium*	0.01
Chloride	250
Chromium (Total)	0.05
Copper*	1.0
Iron (soluble)	0.3
Lead	0.05
Manganese (soluble)	0.05
Mercury*	0.002
Nitrate (as N)	10
Sulfate	250
Total dissolved solids	500
Zinc*	5.0

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* The numeric standards for the chemicals listed above are designed to protect public water supplies for human consumption. The limits established for those chemicals marked with an asterisk (*) may not protect aquatic life. Therefore when a request to classify a stream as a public water supply is received, it will be determined if more stringent limits are needed for those chemicals in order to insure protection of aquatic life.

Of these standards, the general standard, which states that "All wastes shall at all times be free from all substances attributable to sewage, industrial waste, or other wastes in concentrations, amounts or combinations which contravene established standards or interfere directly or indirectly with beneficial use of such water---" was the most relevant to the project. In particular the acidity, and the heavy metallic salts of iron, copper, zinc, manganese, and lead were and are the most significant constituents degrading water quality in Contrary Creek and posed threats to the aquatic environment in Lake Anna downstream.

The objective of this project has been to effectively reduce the pollutional load in the Contrary Creek watershed by eliminating or reducing these sources of pollution to enable Contrary Creek to more closely approach its classification as a Class III stream and meet all Water Quality Standards and Criteria.

SECTION 5

PRERECLAMATION WORK

GRANT APPLICATION

At the request of the SWCB an official from EPA visited the abandoned mine areas in June 1972 to make a preliminary appraisal of the AMD problem. At this time it was determined that the pollution along Contrary Creek would probably qualify for a demonstration grant, but because of pending changes in Federal guidelines the grant was not pursued further for over a year.

In the meantime the SWCB had determined who the property owners of the various mine sites were and had made preliminary contacts with the owners about the proposed reclamation work. The SWCB considered taking legal action against the landowners to alleviate the problem along Contrary Creek but it was feared that the legal course might take longer than pursuing a grant. None of the current property owners had been involved with the former mining activity.

Representatives of the SWCB met again with EPA officials in August 1973 to discuss the problem and further explore the possibilities of obtaining a demonstration grant. Indications from EPA were that the problem should have no trouble meeting the requirements and that chances of a grant being awarded were very good since it involved the control of heavy metals.

Under the provisions of Section 107 of Public Law 92-500 the SWCB decided to apply for an EPA demonstration grant in September 1973 to be used in reclaiming the mine waste areas along Contrary Creek by means of regrading the spoil areas and using wastewater sludge as a soil conditioner. The Commonwealth of Virginia would provide matching funds through in-kind services.

In December 1973 the SWCB retained Gannett Fleming Corddry and Carpenter a consulting firm from Harrisburg, Pennsylvania to prepare a grant application and a feasibility study. Attempting to take advantage of funding for the current fiscal year, the SWCB decided to prepare the grant application using the meager data available and submit it as soon as possible with the feasibility study supporting the application to be submitted later.

A grant application for $654,757 to be used in reclaiming the three mine sites was submitted to EPA in March 1974. The provisions of this application were for 95 per cent Federal funding and 5 per cent State matching funds with all engineering work contracted to a consulting firm and the biologic studies contracted to Dr. George M. Simmons, Jr. of VPI&SU. However, the SWCB was advised in April that the application had been rejected because funds were not available and because energy-related projects were receiving high priority at that time. Shortly afterwards the SWCB was advised by EPA that the grant application might be reconsidered if ways could be found to cut the cost and if the Commonwealth of Virginia could share a larger portion of the cost. In the meantime the consultants continued work on the feasibility study.

While the grant application and feasibility study were in progress Callahan Mining Corporation who had formed a partnership with New Jersey Zinc Company known as Piedmont Mineral Associates contacted the SWCB about an exploration program they were conducting near the Contrary Creek mines. Callahan was considering using the Arminius Site for milling operations provided their exploratory program warranted going into production. Callahan was also interested in recovering valuable metals from the old tailings at the other mine sites along Contrary Creek but after conducting extensive samplings, assayings, and metallurgical tests they determined that this would be uneconomical. However, Callahan advised the SWCB that they were still interested in using the Arminius Site for a milling operation provided their nearby exploration proved successful, and they expressed a willingness to work with the SWCB in reclaiming the Arminius Site.

During the latter part of 1974, the SWCB explored several means of reducing the project costs. The first step taken was for the SWCB to assume responsibility for the biologic studies rather than contract this work, and some of the property owners were approached about sharing part of the cost. The SCS was contacted about what assistance they might be able to provide.

Since the SCS had done some earlier studies at the mine sites and because erosion control was a major part of the problem, it was felt that that agency could lend valuable assistance and could make recommendations for reducing costs. After SCS personnel toured the mine waste areas and reviewed the proposed reclamation methods, they were of the opinion that the scope of the project set forth by the consultants could be reduced considerably. They felt that the channel work proposed downstream between the Route 522 Bridge and Lake Anna would result in only negligible improvement in water quality of Contrary Creek and recommended that no work at all be done along this part of the stream. They proposed only minimal channel work in the immediate vicinity of the mine sites and they also felt that the spoil piles could be regraded and smoothed in preparation for seeding with less disturbance of the existing topography and at less cost than proposed by the consultant.

The Glatfelter Pulp Wood Company, owners of the Sulphur Site, were asked about sharing some of the costs of reclaiming that site but they were reluctant to do so and it was the opinion of the SWCB that they could not legally be compelled to participate. They did agree to plant pine seedlings on the Sulphur Site when restoration work was completed. The SWCB also asked VEPCO about providing some financial assistance, but since they owned only an insignificant portion of property at the mouth of Contrary Creek they felt no obligation to assist. VEPCO did indicate a willingness to help with the monitoring work in the Contrary Creek arm of Lake Anna but this task was eventually assumed by the SWCB.

After Callahan Mining Corporation determined that it would not be economical to recover the abandoned tailings along Contrary Creek, they continued their exploration work east of Route 522. In November 1974 Callahan formally notified the SWCB that they would take responsibility for reclaiming the Arminius Site regardless of whether a decision was made to go into production or not. The consultants had estimated a cost of $127,000 for restoring the Arminius Site. This, of course, meant a considerable reduction in the grant needs.

After several meetings between the consultants, SCS, landowners and EPA, the SCS agreed in November 1974 to provide all engineering services for the project including survey work, preparation of construction plans and specifications and personnel for general and resident inspection. The SCS kindly agreed to provide these services at no cost. Needless to say, this was another tremendous cost savings since the consultants had estimated a total cost of approximately $143,000 for these tasks. The EPA Project Officer advised the SWCB that the participation by SCS did not conflict with grant regulations and that it did not have to be cost itemized in the grant application. By this time the consultants were nearly finished with the feasibility study. The study had been revised to include the downstream reach of Contrary Creek but as mentioned above there was a difference of opinion between the consultant and the SCS on the feasibility of doing this work. The consultant estimated a cost of $221,000 to dredge and realign the downstream reach.

In early 1975 the SWCB prepared and submitted a revised grant application requesting funds to reclaim the Boyd Smith and Sulphur Sites. The total funds requested were $225,158 with the Commonwealth of Virginia providing $150,503 matching funds making the total budget $375,661. This amounted to 60 per cent Federal funding with 40 per cent Commonwealth of Virginia funding. Virtually all of the Federal money requested was to cover construction costs with a very small percentage for contractual personnel services. Table 5 gives more details on the itemized costs in the grant application.

TABLE 5. BUDGET BY COST CATEGORY REQUESTED IN GRANT APPLICATION

Federal Funds		
Construction		$223,718
Contractual Personnel Services		1,440
	Subtotal	$225,158
Commonwealth of Virginia Matching Funds		
Personnel		$ 70,870
Fringe Benefits		16,300
Travel		5,786
Equipment		20,417
Supplies		35,640
Indirect Costs		1,490
	Subtotal	$150,503
Grand Total		$375,661

The objective of the project as set forth in the grant application was to demonstrate methods by which pollutional discharges containing high concentrations of dissolved metals may be abated from two inactive pyrite mines and their pyrite-laden wastes washed into the streambed and flood plain of Contrary Creek. The approach set forth in the grant application provided for the SCS to do the engineering work and described the proposed reclamation of the Arminius Site by Callahan Mining Corporation. The feasibility study was submitted in support of the grant application although as has been pointed out, the scope of the project had been reduced considerably from that proposed in the feasibility study.

FEASIBILITY STUDY

The purpose of the feasibility study was to define the extent of the mine drainage problem along Contrary Creek and Lake Anna, to recommend appropriate abatement measures, and to make cost estimates for the proposed restoration work. The study addressed all three mine sites along with the downstream reach of Contrary Creek between the Sulphur Site and Lake Anna. The consultant conducted several field investigations of the project area during 1974 and the SWCB provided them with all information available including mining history, climatological data, biological and chemical studies, and regulations of the SWCB. The Virginia Department of Highways and Transportation was engaged to do special aerial photography of the project area and that agency also provided existing contour maps for use in defining areas affected by the mine waste. Since only meager chemical data were available, weekly sample collections were made along Contrary Creek at the various mine sites from April until October 1974 to provide additional data to be included in the feasibility study. Sampling continued through the interim period until the regular monitoring program began in October 1975. The water quality data collected over this period continued to show the effects that the leaching of AMD was having upon Contrary Creek. A summary of these data is shown in Table 6.

The feasibility study was completed in December 1974 and a summary of the conclusions drawn is as follows:

1. The demonstration project would meet the requirements of Section 107 of the Federal Water Pollution Control Act.

2. It would be feasible to reduce erosion and leaching of acid and metallic salts originating from three abandoned pyrite mines and from pyrite-laden wastes in the channel of Contrary Creek by restoring waste dumps and by reconstructing stream channels.

3. A considerable volume of pyritic waste material deposited in Contrary Creek downstream from the three mine sites also posed a potential threat to the downstream water quality.

4. Anticipated reductions in the pollutional load should effectively improve the stream quality of Contrary Creek and should substantially remove the potential for flush-outs or acid and dissolved metals

TABLE 6. AVERAGE WATER QUALITY ANALYSES OF CONTRARY CREEK PRIOR TO RECLAMATION (mg/l)[a]

Monitoring Station	pH	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn
Above all Mine Sites	6.8	13	9	0.02	1.1	0.01	0.06	0.2
Below Arminius Site	6.0	12	98	0.11	2.1	0.02	0.52	4.8
Below Boyd Smith Site	4.8	34	149	0.22	2.6	0.03	1.54	3.8
Below Sulphur Site	3.7	126	229	0.76	24.1	0.08	1.71	4.0
Mouth of Contrary Creek	3.3	169	267	1.20	23.1	0.05	1.45	3.5

---

[a] Based upon the average of approximately 25 samples collected in 1974 and 1975.

that could contribute to fish kills and could harm normal aquatic biota in Lake Anna.

5. A proposed monitoring program would define the extent of the mine drainage problem, and the data obtained would establish the effectiveness of the demonstration project and would aid in determining any remaining pollutional loads that would have to be abated to achieve desired stream quality.

6. Accurate cost records obtained from the project would have potential future use for abatement methods on similar areas.

7. Existing legislation and the easements to be obtained for this project would protect the restored sites.

A summary of the recommendations made in the feasibility study are as follows:

1. Regrade the pyritic waste disposal areas to maximize surface runoff, minimize erosion and promote vegetative growth.

2. Dredge and realign portions of Contrary Creek and tributaries and construct diversions within the mine sites.

3. Conduct soil analyses and apply lime and fertilizer as needed.

4. Place wastewater sludge on the regraded areas and seed.

5. Dredge and realign all of Contrary Creek and portions of tributaries downstream between the Sulphur Site and Lake Anna.

6. Conduct an extensive monitoring program which would include the construction of 5 flow gaging stations along Contrary Creek and establish 2 sample stations in the Contrary Creek arm of Lake Anna. Collect grab samples from all monitoring and sample stations periodically to be analyzed for pH, alkalinity, acidity, sulfates, turbidity, suspended solids, iron, copper, zinc, manganese and lead. It was further recommended that analyses for BOD and fecal coliform be conducted at all stations after wastewater sludge was applied. Continuous precipitation records were also to be compiled.

7. Cost records be compiled so that actual abatement costs could be determined.

8. All precautions should be taken during construction to minimize flooding, sedimentation and pollution problems.

SITE EASEMENTS

Under the provisions of Section 107(d) of PL-92-500, the SWCB secured agreements with the owners of the mine sites prior to beginning the reclamation work. Section 107(d) states:

"(1) that the State shall acquire any land or interest therein necessary for such project; and

(2) that the State shall provide legal and practical protection to the project area to insure against any activities which will cause future acid or other mine pollution."

As mentioned earlier, the SWCB had determined who the property owners were and had contacted them about the proposed reclamation work during the initial planning stages. The Sulphur Site is part of a 650-hectare tract owned by the Glatfelter Pulp Wood Company and the Boyd Smith Site is privately owned by Mrs. Otelia Mallory who resides on the property.

While the grant application and feasibility study were being prepared, the Office of the Attorney General of the Commonwealth of Virginia with the assistance of the SWCB drafted deeds of easement to be executed with each property owner. The deeds of easement covering a period of 5 years provided for the necessary reclamation work and the construction of flow recording stations and stipulated that the owners would not conduct any activity that would adversely affect the project goals or objectives. The Glatfelter Pulp Wood Company requested a special provision in their agreement which would not prevent them from planting trees on the reclaimed areas, and the Mallory easement was modified to provide for a lease agreement with Piedmont Mineral Associates. A copy of the general provisions of the agreement appears in Appendix A.

Separate agreements were executed with New Jersey Zinc Company to provide for access to the Arminius Site and with another property owner to allow for the construction of a flow gaging station upstream from all the mine sites. No serious problems were encountered in securing the easements other than the property owners asking for some additional information and requesting that a few minor changes be made in the agreements. Initially, a preliminary memorandum of understanding was proposed with the owners prior to execution of the formal property agreement, but the owners felt that the proposed agreement was too broad, unclear and committed them to signing another agreement which they had not seen. In light of this circumstance the SWCB decided to proceed with the execution of the final deeds of easement which were all signed prior to the beginning of the construction work. Deeds of easement were recorded in the Louisa County Courthouse.

PLANS AND SPECIFICATIONS

In June 1975 the SWCB was notified by EPA that the Contrary Creek grant application had been selected for award. With the aid of large scale mapping provided by the VDH&T and by field surveys, the SCS drafted plans and specs for restoring the Boyd Smith and Sulphur Sites and prepared a bidding document. The general outline of the reclamation plan developed by the SCS follows:

(1) Clearing of waste areas

(2) Grading and smoothing

(3) Constructing diversions and waterways

(4) Salvaging and spreading topsoil

(5) Excavating channels

(6) Placing loose riprap stone

(7) Spreading wastewater sludge

(8) Seeding and planting

(9) Providing erosion control

All plans and specs were submitted to EPA for approval and the bid document was reviewed by the Virginia Office of the Attorney General before invitations to bid were advertised. The bid package provided for all construction work necessary to reclaim the mine sites except furnishing of riprap material and hauling of wastewater sludge.

BID ADVERTISING AND AWARD OF CONTRACT

Invitations to bid were advertised in 6 area newspapers and approximately 75 potential bidders were notified by mail. Interested contractors were shown the site in January 1976. Sixteen contractors submitted bids. The bids were opened on 3 February 1976 and ranged from a low of $87,922.50 to a high of $180,687.50. Several of the contractors in the low bid range were asked to submit additional information on their firm before a final decision was made. After this review was made and the SCS had conducted equipment inspections, the contract was awarded to Sellers Brothers, Inc. of Danville, Virginia who had submitted the lowest bid. The contractor was given notice to proceed with work at the beginning of April 1976 and to have all work completed within 150 calendar days as specified in the bid document.

A separate contract was negotiated with a local quarry for furnishing riprap stone and bedding. In lieu of public advertising, local stone suppliers were sent invitations to quote a price on furnishing and delivering the stone material to the project site. The low bid of $11,913.90 was submitted by A. H. Smith Stone which operates a quarry developed in granitic rocks approximately 4 kilometers west of the project area.

ACQUISITION OF WASTEWATER SLUDGE

The SWCB began exploring for sources of wastewater sludge well before the construction contract was awarded. The consultant estimated in the feasibility study a cost of about $10 per metric ton for transporting sludge. Several municipalities within hauling distance of the project site were considered, but only the cities of Richmond and Washington, D.C. generated digested sludge in the volumes needed. The City of Richmond made a detailed cost analysis, and advised the SWCB that they could haul sludge to the site for approximately $4 per tonne (metric ton). Richmond was seriously considered as a sludge source but in the meantime the SWCB had contacted officials from the District of Columbia about obtaining sludge from the Blue Plains Wastewater Treatment Plant in Washington, D.C. Initially, the District estimated a cost of about $2 per tonne for hauling sludge but shortly before beginning of construction work the District advised the SWCB that they could provide all the sludge needed at no cost for hauling. Needless to say, this represented another substantial cost savings. The Blue Plains Plant generates approximately 275 tonnes of anaerobically digested sludge daily. The sludge from this plant is concentrated by vacuum filtration to approximately 20 per cent solids. Land costs for disposal of sludge in the Washington, D.C. metropolitan area are so high that the District of Columbia Government incurred little if any extra expense in hauling sludge an additional 80 or 90 miles to the project where, of course, there was no charge for disposal.

MONITORING PROGRAM

A comprehensive monitoring program implemented prior to reclamation to determine the effectiveness of the project continued until early 1980 when it was reduced in scale. Monitoring stations were established as recommended by the consultant in the feasibility study. Five monitoring stations were established along Contrary Creek and two sampling points were established in the Contrary Creek arm of Lake Anna. All stream monitoring stations were equipped with continuous flow recorders except for one station at the mouth of Contrary Creek where channel conditions were too unstable for installing a flow gaging station. The four automatic recording stations were installed and maintained by the SWI section of the SWCB.

All regular sample collections were conducted by personnel from the Piedmont Regional Office of the SWCB and analytical work was done by the DCLS as part of the matching funds. In addition to the regular water quality and flow monitoring, special studies were done to determine effects of storm runoff and to pinpoint specific sources of AMD along the main channel of Contrary Creek and its tributaries. Biologic studies were conducted semi-annually by the DES of the SWCB. Various soil analyses have been performed periodically by the SCS and the DCLS and a special study on metals uptake of vegetation was done by a private firm contracted by EPA. Sludge samples were collected daily during the main phase of reclamation work in 1976 and analyzed by DCLS. Results of all monitoring are discussed in Section 9 of this report.

SECTION 6

RECLAMATION WORK - 1976

Reclamation work began at the Boyd Smith and Sulphur Sites in early April 1976. Wet ground caused some delay at the Boyd Smith Site but work progressed more or less concurrently at both sites. The SCS provided an on-site inspector for the duration of the construction and seeding work along with engineering and agronomic expertise.

For the purpose of this report the various work areas of the Sulphur Site have been named as depicted in Figure 13.

CONSTRUCTION

The first phase of construction consisted of clearing the waste areas of snags, stumps, brush, rubbish and a few unavoidable pine trees. Special care was taken to preserve all trees possible including the test plots at the Boyd Smith Site (Figure 14). All clearing work was done with two D-8 bulldozers.

Regrading and smoothing work was done with the two bulldozers along with two 175 endloaders and one 955 loader (Figures 15 and 16). At the Sulphur Site a considerable amount of the wastes was pushed or dumped into some of the old pits and shaft entrances. Since not all of the exact locations of the old shaft entrances were known at the Sulphur Site, there was concern as to what danger this might pose for heavy equipment. Fortunately, no cave-in problems occured. Another concern was the possibility of encountering resistant hardpan under some of the old tailing piles, but again this problem did not materialize. A small amount of the fine tailings from Sulphur West was trucked to the east side to add some extra fines to the predominantly coarse material there.

The spoil areas at both sites were graded to approximately the natural contours (Figure 17). It is estimated that approximately 67,000 cubic meters of tailings and reject material were regraded and smoothed at both sites. This figure is based upon the pre-construction estimate made by the SCS. The grading and smoothing work progressed considerably faster than expected and was completed at both sites within two months.

Construction of diversions and waterways to shorten slopes and to minimize runoff infiltrating into the mine wastes and underground workings was done concurrently with the grading and smoothing work. Locations of diversions and waterways at the Sulphur Site are shown in Figure 18. At the Boyd Smith Site the main drainageway traversing the site was excavated and realigned, and a diversion was constructed on each side of the site to facilitate drainage so that the ground would support heavy equipment (Figure 19).

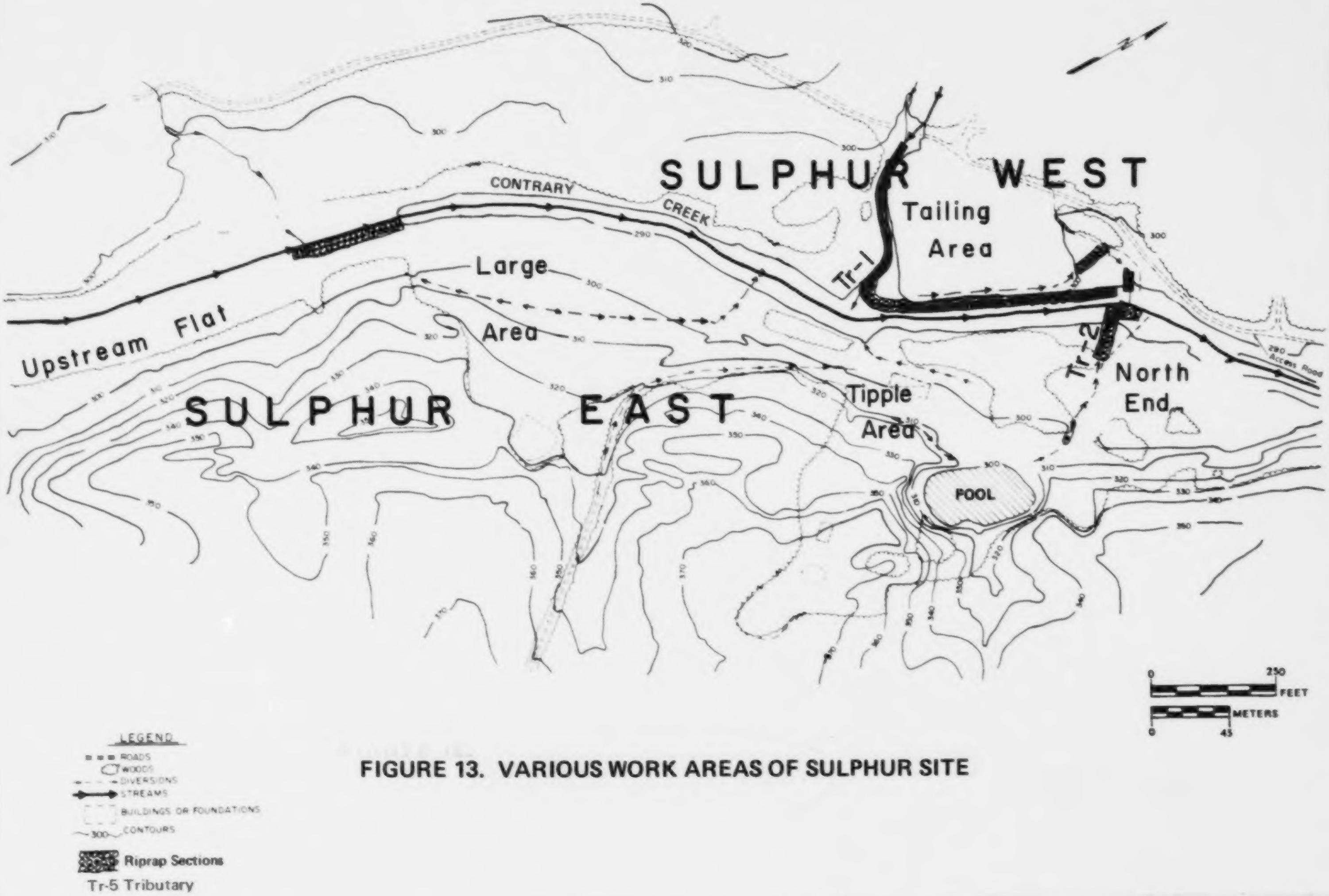

FIGURE 13. VARIOUS WORK AREAS OF SULPHUR SITE

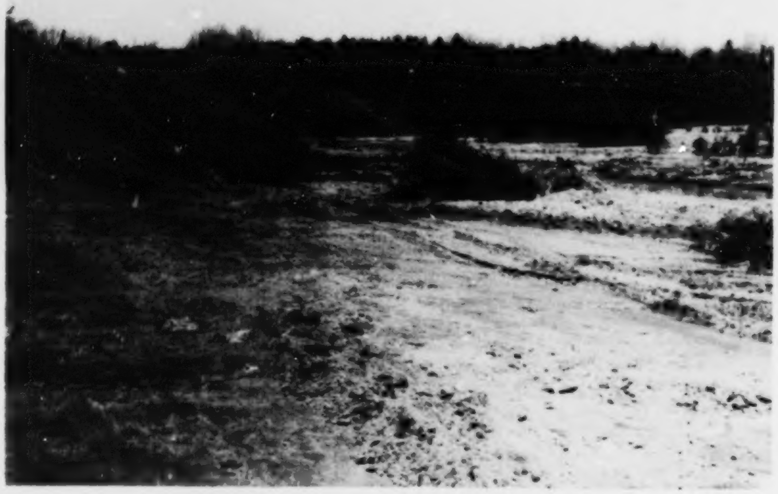

Figure 14. Clearing and regrading of Boyd Smith Site April 1976.

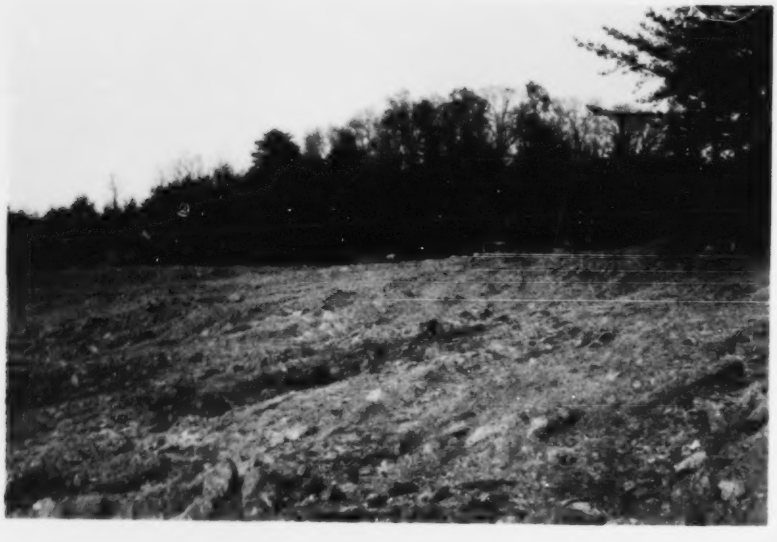

Figure 15. Regrading of Large Area at Sulphur East Spring 1976.

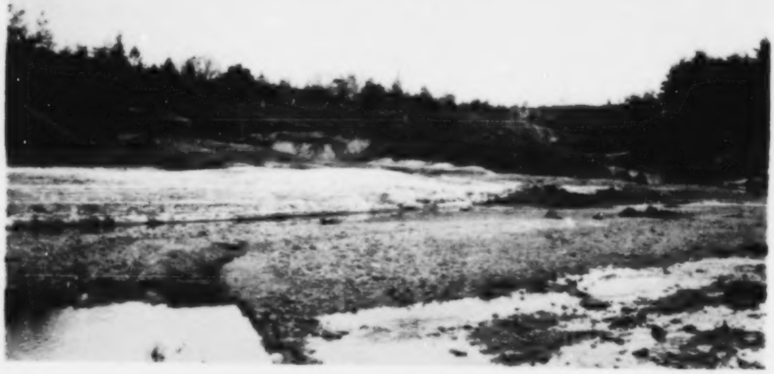

Figure 16. Regrading of tailing pile at Sulphur West Spring 1976.

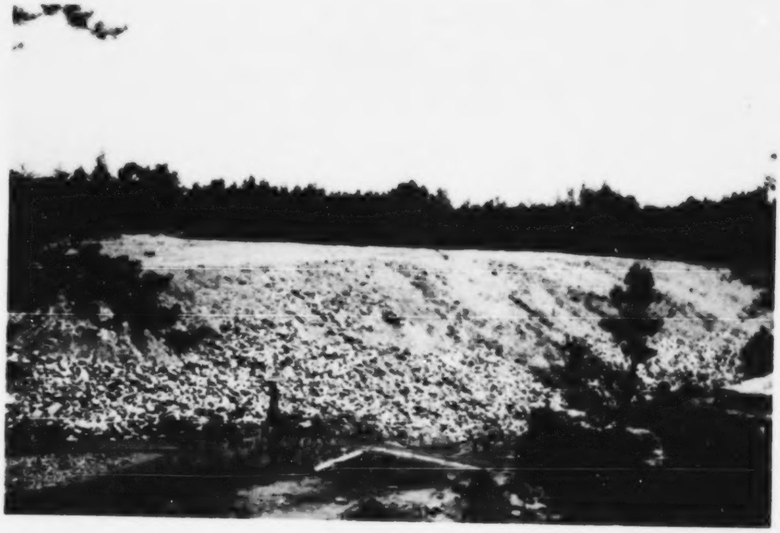

Figure 17. Regraded tailings at Sulphur West - Summer 1976. Same view as shown in Figure 11 prior to reclamation.

TYPING GUIDE SHEET

SULPHUR SITE

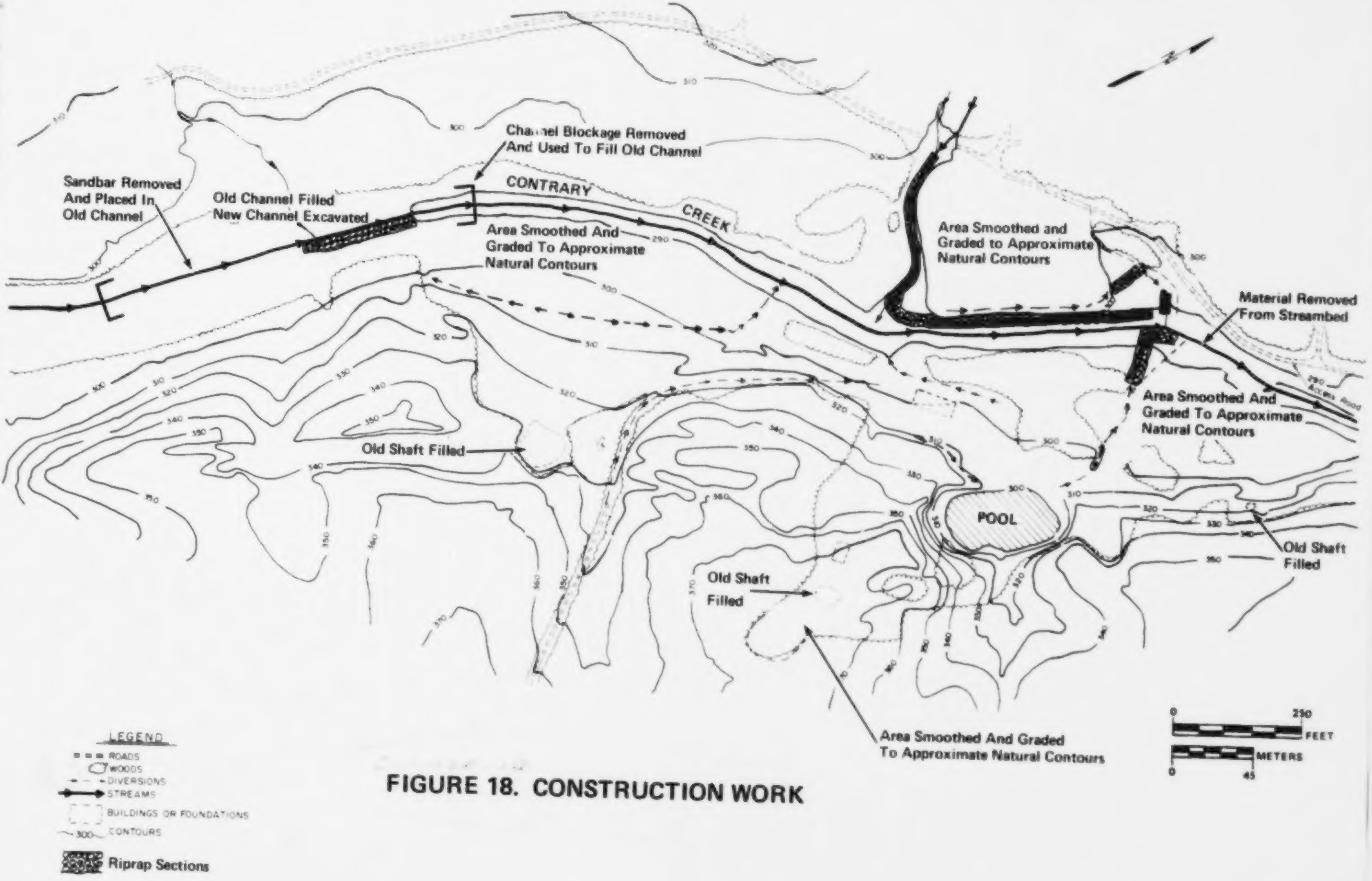
Sandbar Removed And Placed In Old Channel
Old Channel Filled New Channel Excavated
Channel Blockage Removed And Used To Fill Old Channel
CONTRARY CREEK
Area Smoothed And Graded To Approximate Natural Contours
Area Smoothed and Graded to Approximate Natural Contours
Material Removed From Streambed
Area Smoothed And Graded To Approximate Natural Contours
Access Road
Old Shaft Filled
POOL
Old Shaft Filled
Old Shaft Filled
Area Smoothed And Graded To Approximate Natural Contours
N
300
310
320
330
340
350
360
370
290
0
250
FEET
METERS
45
LEGEND
ROADS
WOODS
DIVERSIONS
STREAMS
BUILDINGS OR FOUNDATIONS
300 CONTOURS
Riprap Sections

FIGURE 18. CONSTRUCTION WORK

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TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

BOYD SMITH SITE

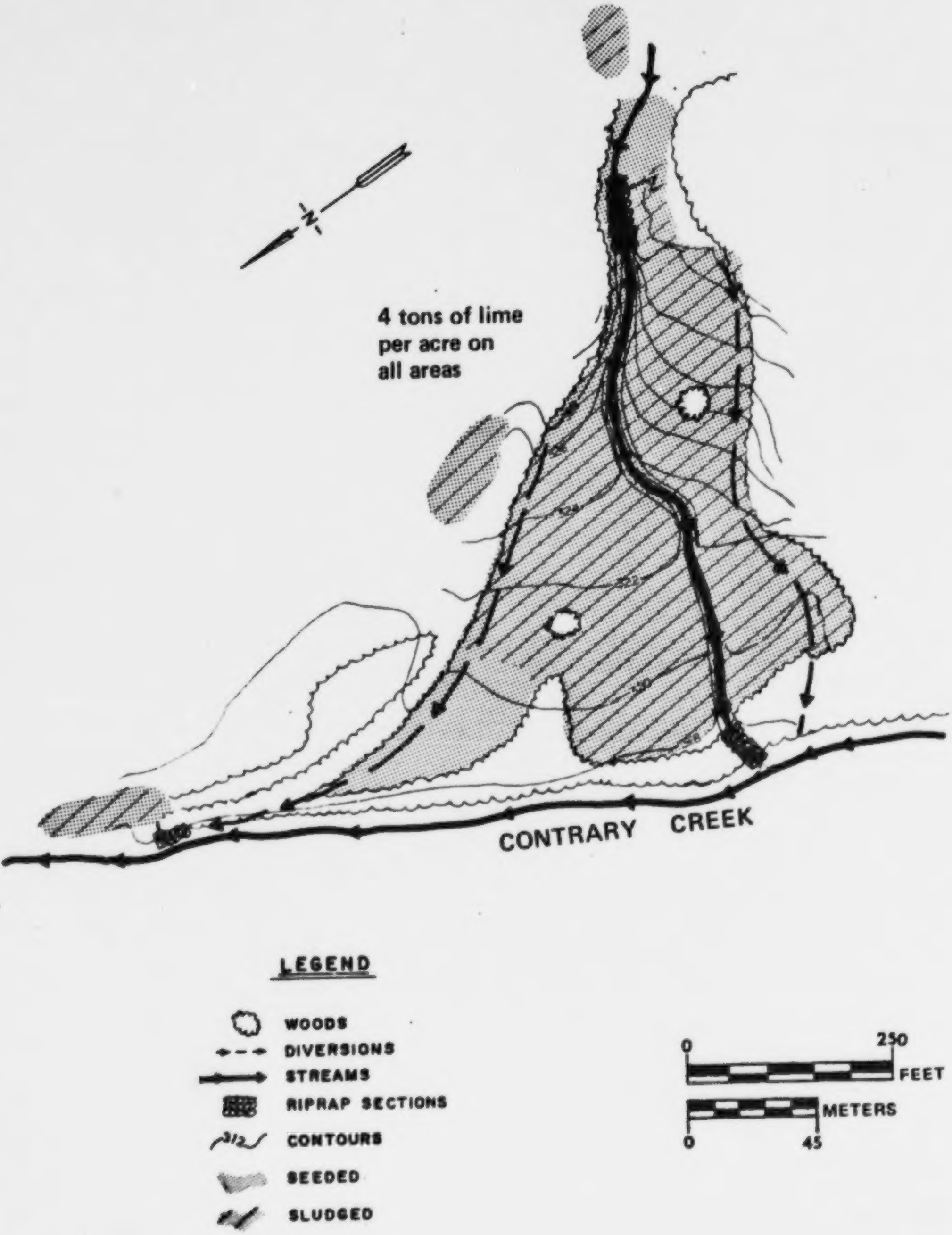

FIGURE 19. CONSTRUCTION AND SEEDING WORK – SUMMER 1976
(All areas were reseeded in spring of 1977)

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
PAGE NUMBER

Another part of the construction work at the Sulphur Site consisted of straightening the channel of Contrary Creek and excavating toxic materials from major portions of the streambed. All of the main channel along the Upstream Flat of Sulphur East was relocated and straightened and several hundred feet of the channel was excavated in the vicinity of the Tailing Area (Figure 20). Initially the channel work was attempted with a backhoe but this machine proved unsatisfactory working from the high stream banks. At the recommendation of the SCS engineer the backhoe was replaced with a crawler mounted crane equipped with a dragline bucket and clamshell. The dragline allowed for greater length of reach and proved much more efficient. The diversions at the Boyd Smith Site were also excavated with the dragline because wet ground limited the use of the backhoe.

Approximately 1400 tonnes of stone from a nearby granite quarry were used at both sites to stabilize stream banks and to line diversions in the 1976 work (Figure 21). This included 1100 tonnes of Class I dry riprap and 300 tonnes of No. 25 graded aggregate for bedding. The stone size was in accordance with VDH&T specifications. Stone was hauled directly to the placement areas by the supplier and placed by the contractor. Virtually all riprap and bedding materials were placed with the dragline. The largest section of riprap was placed over the old cribbing adjacent to the Tailing Area of Sulphur West and along the full length of Tr-1 in the disturbed area (Figure 18). Additional sections of riprap were added at the Sulphur Site in 1977 and 1978. At the Boyd Smith Site sections of riprap were placed at the mouth of each tributary draining into Contrary Creek and along the upper reach of the main tributary near the old shafts (Figure 19). Typical dimensions of the riprap sections used at both sites are shown in Figures 22 and 23.

APPLICATION OF SLUDGE AND OTHER SOIL AMENDMENTS

The use of municipal sludge in mine reclamation is relatively rare. Few projects are known to have utilized sludge on the scale that has been done at Contrary Creek. Municipal sludge has several characteristics that make it desirable for use in mine reclamation. One of its most important constituents is organic matter which when incorporated into mine spoils increases the water holding capacity, increases the cation absorption capacity, and improves the supply and the availability of nutrients (Hill, 1977).

Before delivery of sludge to the project site began the SWCB provided the Government of the District of Columbia with written authorization and all applicable hauling regulations from the VDH&T. Guidelines for the disposal of sludge were obtained from the Virginia Department of Health. The hauling route was designated so as to minimize travel through populated areas, and the hauling distance was approximately 275 kilometers (170 miles) per round trip. Sludge was hauled in 18-tonne-capacity trucks partially covered with tarpaulins. Usually, 10 loads of sludge were hauled each day with 5 trucks making 2 trips each. Delivery of sludge began around mid-April and continued regularly for 2 months except for a few occasions when wet ground curtailed operations. Approximately 400 truckloads of sludge amounting to about 7250 tonnes were delivered to both mine sites. Initially it was anticipated that some stockpiling of sludge might be necessary, but unusually

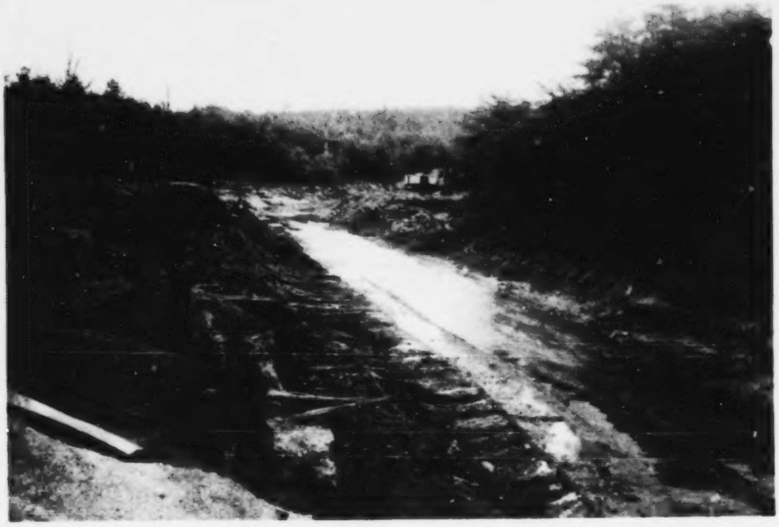

Figure 20. Excavation of mine wastes from stream channel along Tailing Area at Sulphur West.

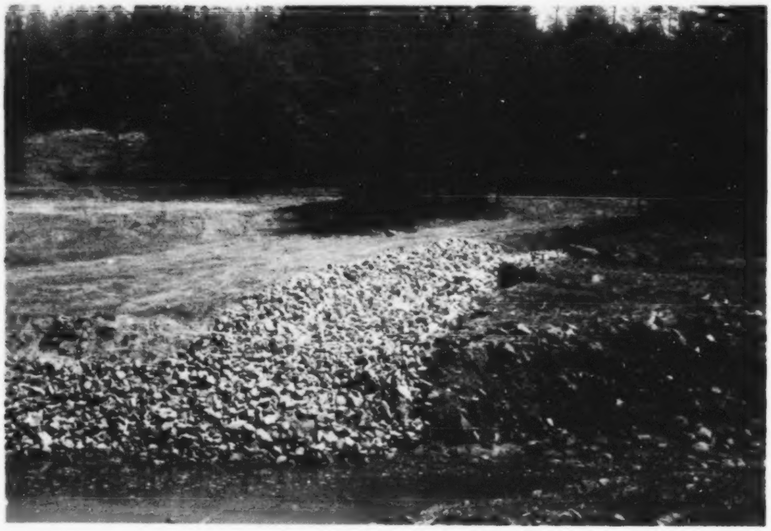

Figure 21. Riprap section at mouth of Tr-2 at Sulphur East.

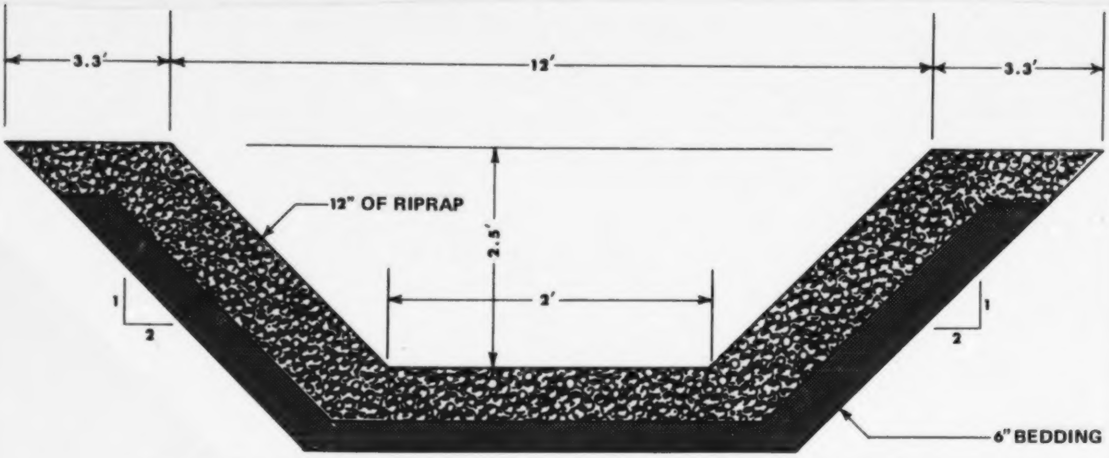

FIGURE 22. TYPICAL RIPRAP SECTION USED IN DIVERSIONS
(NOT TO SCALE)

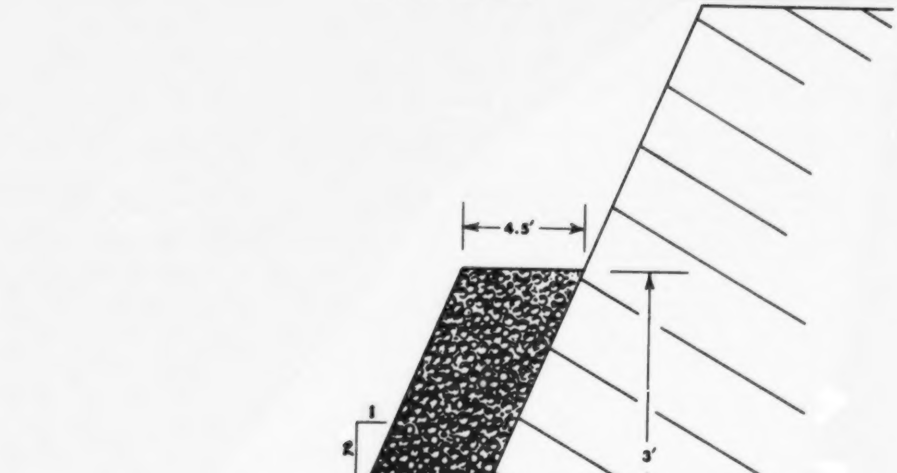

FIGURE 23. TYPICAL RIPRAP SECTION USED ALONG STREAMBANKS
(NOT TO SCALE)

dry weather during the spring of 1976 and an agreement with the hauler to deliver sludge on an as-needed basis minimized stockpiling. Virtually all of the sludge was dumped directly upon the regraded areas where it was to be incorporated (Figure 24).

Before sludge was spread and worked into the regraded areas, lime and fertilizer were applied to all areas to be reseeded. A spreader truck was used to apply lime to all areas except on steep slopes and soft places along the stream banks where it was necessary to hand spread. Lime was applied at the rate of 9 tonnes per hectare (4 tons/ac), and 10-10-10 fertilizer was applied at the rate of 1120 kilograms per hectare (1000 lbs/ac) to all areas. In addition to the 10-10-10 fertilizer 38-0-0 (ureaform) fertilizer was applied at the rate of 448 kilograms per hectare (400 lbs/ac) to the unsludged areas. (Table 7).

TABLE 7. LIME AND FERTILIZER APPLICATION RATES - 1976

Lime	9 tonnes/ha[a]
Fertilizer	
All areas 10-10-10	1121 kg/ha
Unsludged areas 38-0-0 (ureaform)	448.4 kg/ha

[a] To convert tonnes/ha to tons/ac multiply by 0.449.
[b] To convert kg/ha to lbs/ac multiply by 0.892.

Sludge was generally allowed to dry for up to a week prior to spreading, but in some cases spreading was done a day or two after delivery. It would have been desirable for sludge to have dried longer before spreading, but this was not feasible due to time constraints. Bulldozers were used to spread the sludge to a thickness of approximately 10 centimeters (Figure 25). It was found that spreading could be done much more efficiently by backdragging rather than pushing. A heavy-duty Rome disc drawn by a bulldozer was used to incorporate the sludge along with the other soil amendments into the spoil material to a depth of 8 to 16 centimeters. Where the ground was too soft to support heavy equipment, a small disc pulled by a farm tractor was used to incorporate sludge. Approximately 1.2 hectares of the Sulphur Site including the Upstream Flat of Sulphur East and a few places along the stream banks that were too soft to support any equipment were not sludged in 1976.

A total of 5443 tonnes of wet sludge was applied to 4.6 hectares of the Sulphur Site and a total of 1814 tonnes to 2 hectares of the Boyd Smith Site. As determined by laboratory analyses, the average moisture content of the sludge used during the summer of 1976 was 78 per cent. The actual dry tonnes applied are shown in Table 8.

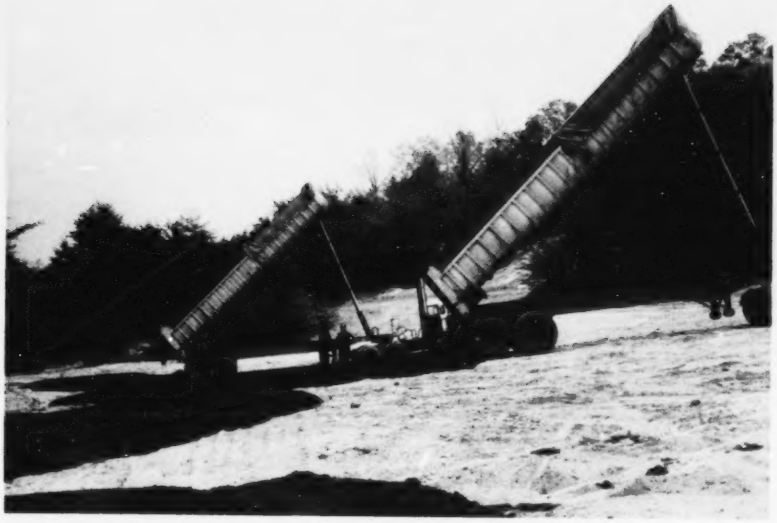

Figure 24. Dumping sludge at Sulphur Site.

Figure 25. Spreading sludge at Sulphur Site.

TABLE 8. SLUDGE APPLICATION RATES - 1976

Sulphur Site	260 dry tonnes/ha[a]
Boyd Smith Site	200 dry tonnes/ha

[a] To convert tonnes/ha to tons/ac multiply by 0.449.

Special care was taken during all phases of the operation to prevent sludge from entering into Contrary Creek or any of its tributaries. Trucks were directed to dump a safe distance from all stream banks and in some places low berms were constructed as a further protection. There was concern that there might be a problem with sludge being washed into the main stream and tributaries in the event a heavy rain fell while sludge was drying, but it was found that sludge tended to cohere when wet and did not flow appreciably. Where possible, some sludge was applied to stream banks but inaccessibility kept this to a minimum. Trucks were carefully cleaned after each dumping to prevent loss of sludge on public highways.

As part of the project monitoring, samples were collected from each truckload of sludge and composited into one daily sample during the 1976 work. There was little variation in the composition of the sludge from day to day but moisture content varied as much as 8 per cent. This variation can mainly be attributed to the sludge being stored in the open for a day or so before hauling, and there is some slight variation in moisture content of the sludge from the treatment plant. Sludge samples were analyzed by the Division of Consolidated Laboratory Services, the same laboratory that has conducted all of the water and soil analyses for the project. Average concentrations of the constituents in the Contrary Creek sludge based upon 40 composite samples collected during the 1976 work are shown in Table 9.

The heavy metals content of the Blue Plains sludge is within the range of that reported for sludge from other municipal sewage treatment plants and tends to be lower than that from highly industrialized cities. The high iron content of the Blue Plains sludge is partly due to ferric chloride used in the treatment process. The average pH of the sludge was 6.5 and volatile solids averaged 51 per cent. Fertilizer equivalent values were also determined for the sludge and averages for the composite samples in the summer of 1976 are shown in Table 10. Additional sludge data appears in Section 9 of this report.

TABLE 9. AVERAGE CONCENTRATIONS OF CONSTITUENTS IN THE SLUDGE USED AT CONTRARY CREEK IN 1976 ON DRY WEIGHT BASIS

Constituent	ppm
Alkalinity	17
Cl (Soluble)	8.1
Cd	17
Cr	659
Cu	785
Fe	109,000
Pb	550
Hg	5.05
Zn	2,529
Ni	29
F (Soluble)	0.73

TABLE 10. AVERAGE FERTILIZER EQUIVALENTS OF SLUDGE USED AT CONTRARY CREEK IN 1976 ON DRY WEIGHT BASIS

Nutrient	Per cent
N	3.23
P_2O_5	7.32
K_2O	0.32

SEEDING

Seeding began in late June and was completed at both sites by early July. While it was realized that this was not the most favorable season for planting, it was not feasible to delay the seeding since the regrading and smoothing work had progressed considerably faster than expected. After all soil amendments had been incorporated, the seedbed was smoothed by dragging heavy timbers over rough areas as a final preparation. A tractor-drawn Brillion cultipacker was used to do all seeding except for steep banks and soft spots that had to be hand seeded. The seed formula included two grasses, Ky-31 fescue and red top, along with ladino clover for a legume. Seed species and application rates are given in Table 11. Figure 26 shows seeded and sludged areas of the Sulphur Site. Refer to Figure 19 for seeding done at the Boyd Smith Site.

In addition to the specified seed formula, 24 kilograms of deertongue grass were sown randomly over various areas of Sulphur East at the recommendation of the SCS agronomist. Immediately after seeding, mulch comprised of small grain straw was applied at the rate of 5 tonnes per hectare with a mulching machine and tied down with emulsified asphalt.

TABLE 11. SEED SPECIES AND APPLICATION RATES - 1976

Species	Kg/ha[a]
Tall Fescue (var. Ky-31)	67
Red Top	5.6
Ladino Clover	5.6

[a] To convert Kg/ha to lbs/ha multiply by 0.892.

After all construction was completed, several straw bales were staked in drainageways and along stream banks to control erosion until vegetation had a chance to establish, but by late summer it was realized that additional erosion controls would be needed. Approximately 300 straw bales were placed at erosion prone areas on both sides of the Sulphur Site in October, 1976.

COSTS

All construction and seeding work was performed by Sellers Brothers, Inc. and included the furnishing of all materials except stone and sludge. Payment for construction was based upon the hourly rate for equipment rental as agreed to in the contract. Payment for seeding including all lime, fertilizer, seed, mulch and asphalt tiedown was at the rate of $600 per acre. The SCS inspector logged equipment hours daily and measured acreage at the completion of seeding. A summary of the construction and seeding costs appears in Table 12.

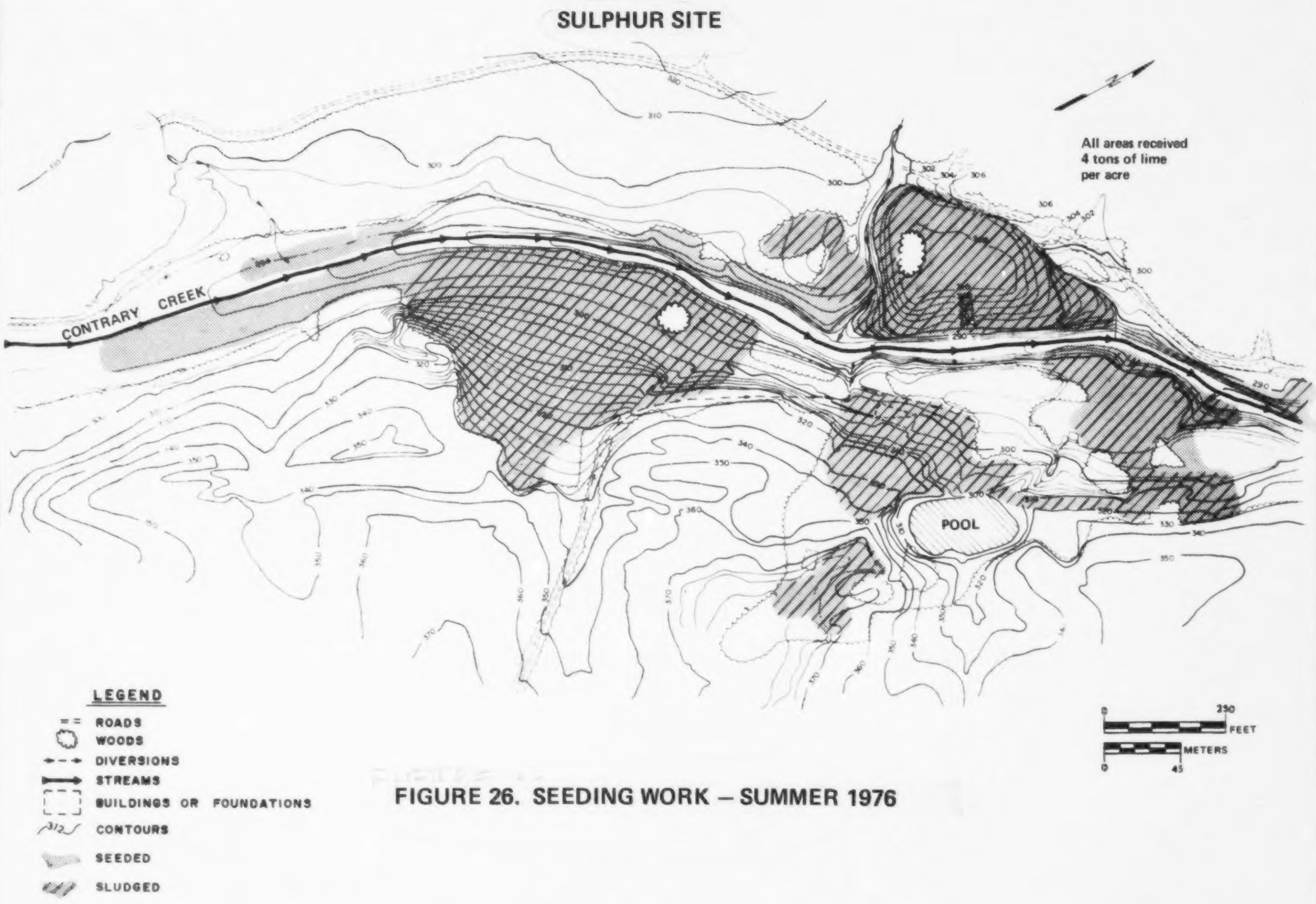

FIGURE 26. SEEDING WORK – SUMMER 1976

The original contract called for 3 D-8 bulldozers, but as grading progressed more rapidly than expected it was decided by the SCS engineer that one bulldozer could be eliminated and that the estimated hours could be reduced on another bulldozer. In place of these hours were added a crane, a farm tractor with attached disc, and a water truck. As stated above, the crane was much more effective than the backhoe for working on stream banks and the tractor drawn disc was needed in areas inaccessible to bulldozers. The water truck was added for dust control.

The only other contract negotiated in connection with the 1976 reclamation work was with A. H. Smith Stone for the furnishing and delivery of riprap and bedding material. Table 13 gives a breakdown of stone costs. Total cost of the construction and seeding work was $64,863.90 as shown below.

Sellers Brothers	$55,709.50
A.H. Smith Stone	$ 9,154.40
Total	$64,863.90

Sellers Brothers had bid $87,922.50 for the job and A. H. Smith Stone had bid $11,913.90 for furnishing stone.

The contract with Sellers Brothers, Inc. included the planting of pine seedlings at the Boyd Smith Site, but this work was carried over until the spring of 1977 when the season would be optimum for planting.

RESULTS

The success of the 1976 seeding work was very limited. It was realized that late June and early July were not optimum times for planting and the problem was further compounded by below average rainfall during the remainder of the growing season. This was particularly so in July, and by the time a few heavy thunderstorms came in August, much of the grass that had germinated had died. Only in the more shaded areas did the grass show any degree of success.

It came as no surprise that conditions at the Sulphur Site were by far the poorest. The only areas that showed any significant cover of grass by the end of the summer were some of the shaded areas on Sulphur East. The Large Area of Sulphur East produced a heavy growth of tomatoes during the late summer, but after the first frost only a few patches of vegetation remained around the edges that had been shaded. Virtually no germination occurred on the Tailing Area of Sulphur West even though sludge had been applied heavily. None of the unsludged areas on either side of the Sulphur Site showed any signs of germination.

At the Boyd Smith Site the results of the 1976 work were more encouraging. A fair growth of vegetation established on some parts of the site, but the dry weather took its toll here also despite the ground remaining somewhat wetter than the Sulphur Site. Sludge had been applied to all of the Boyd Smith Site, but of the seeds planted, only the Ky-31 showed any success.

TABLE 12. SUMMARY OF CONSTRUCTION AND SEEDING COSTS - 1976 [a]

EQUIPMENT RENTAL

Type Equipment	No. of Pieces	No. Hours Used	Cost Per Hour	Total Cost
D-8 150 dozer	1	184	$29.00	$ 5,336.00
D-8 100 dozer	1	182	22.50	4,095.00
175 loader	2	498.5	23.00	11,465.50
955 loader	1	183	21.00	3,843.00
Crane	1	312.5	40.00	12,500.00
Backhoe	1	79	35.00	2,765.00
Rome disc	1	65	2.00	130.00
Farm tractor & disc	1	43	25.00	1,075.00
Dump truck	1	32	12.50	400.00
Water truck	1	27	10.00	270.00
Power saw	1	20	6.50	130.00
Subtotal	12	1626		$42,009.50

SEEDING

Site	No. Acres Seeded	Cost per Acre	Total Cost
Sulphur	14.5	$600	$8,700.00
Boyd Smith	5	$600	3,000.00
Subtotal	19.5		$11,700.00
MOBILIZATION			$ 2,000.00
		Grand Total	$55,709.50

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[a] Does not include cost of stone.

TABLE 13. SUMMARY OF STONE COSTS

Type Stone	No. Tons Used	Cost per ton	Cost
Riprap	1090.01	$7.50	$8175.08
Bedding	240.70	3.15	758.20
	71.33	3.10	221.12
		TOTAL	$9154.40

By late summer it was apparent that complete reseeding would be necessary in the spring of 1977, and an abnormally cold fall further aggravated the problem. Overriding the weather problems was the fact that major portions of the Sulphur Site still remained highly toxic. As an added protection against erosion in critical areas of the Sulphur Site, approximately 285 straw bales were staked in drainageways and along stream banks. This work was done by a local contractor on a non-bid sole source basis at a lump sum of $845. Maintenance work conducted since 1976 is discussed in the next section.

SECTION 7

MAINTENANCE

An ongoing maintenance program has continued since the major reclamation work of 1976. Maintenance work has included the application of more sludge, lime, and fertilizer; reseeding of problem areas; and the placing of additional riprap and straw bales to control erosion. All of the Sulphur and Boyd Smith Sites were reseeded in the spring of 1977 and spot seeding of problem areas has been continued each fall and spring to date. Soil samples have been collected and analyzed periodically from both sites to determine lime and fertilizer requirements. A summary of sludge, lime, and fertilizer application and soil analyses is presented in Section 9.

All of the maintenance work has been done by local contractors except for the spring 1977 work which was performed by Sellers Brothers, Inc. The SCS has continued to assist the SWCB with maintenance work by providing technical advice and inspection services. Virtually all of the SCS assistance since 1977 has been provided by the Louisa County Field Office. Plans and specifications for all maintenance work have been prepared with the assistance of the SCS and approval of the EPA Project Officer.

SPRING 1977

The spring of 1977 work consisted of the application of additional lime and fertilizer, reseeding of both sites, and placing a new section of riprap at the Sulphur Site. Since the contract with Sellers Brothers was still open providing for the planting of pine seedlings at the Boyd Smith Site, all of the spring maintenance work was done under a contract modification with the exception of furnishing stone.

Lime application rates were determined by titration analyses of composite soil samples. A discussion of analytical procedures is given in Appendix B. Lime was applied by spreader truck at rates ranging from 13.3 to 31.2 tonnes per hectare (6 to 14 tons/ac) on the Sulphur Site (Figure 27) and at a rate of 9 tonnes per hectare (4 tons / ac) on the Boyd Smith Site.

Four different types of fertilizer were used including the 10-10-10 and 38-0-0 types used the previous summer along with 907 kilograms (1 ton) each of 16-7-12 and 18-18-6 controlled release fertilizers which were donated by the Sierra Chemical Company to compare with other fertilizers. Each type of controlled release fertilizer was applied to designated portions of both sites totaling about 3.2 hectares. This included 2.4 hectares that had received sludge the summer before and 0.8 hectare along the stream banks of the Sulphur Site that had not been sludged. Unfortunately, extensive maintenance since 1977 has probably obscured any pronounced results the controlled release

SULPHUR SITE

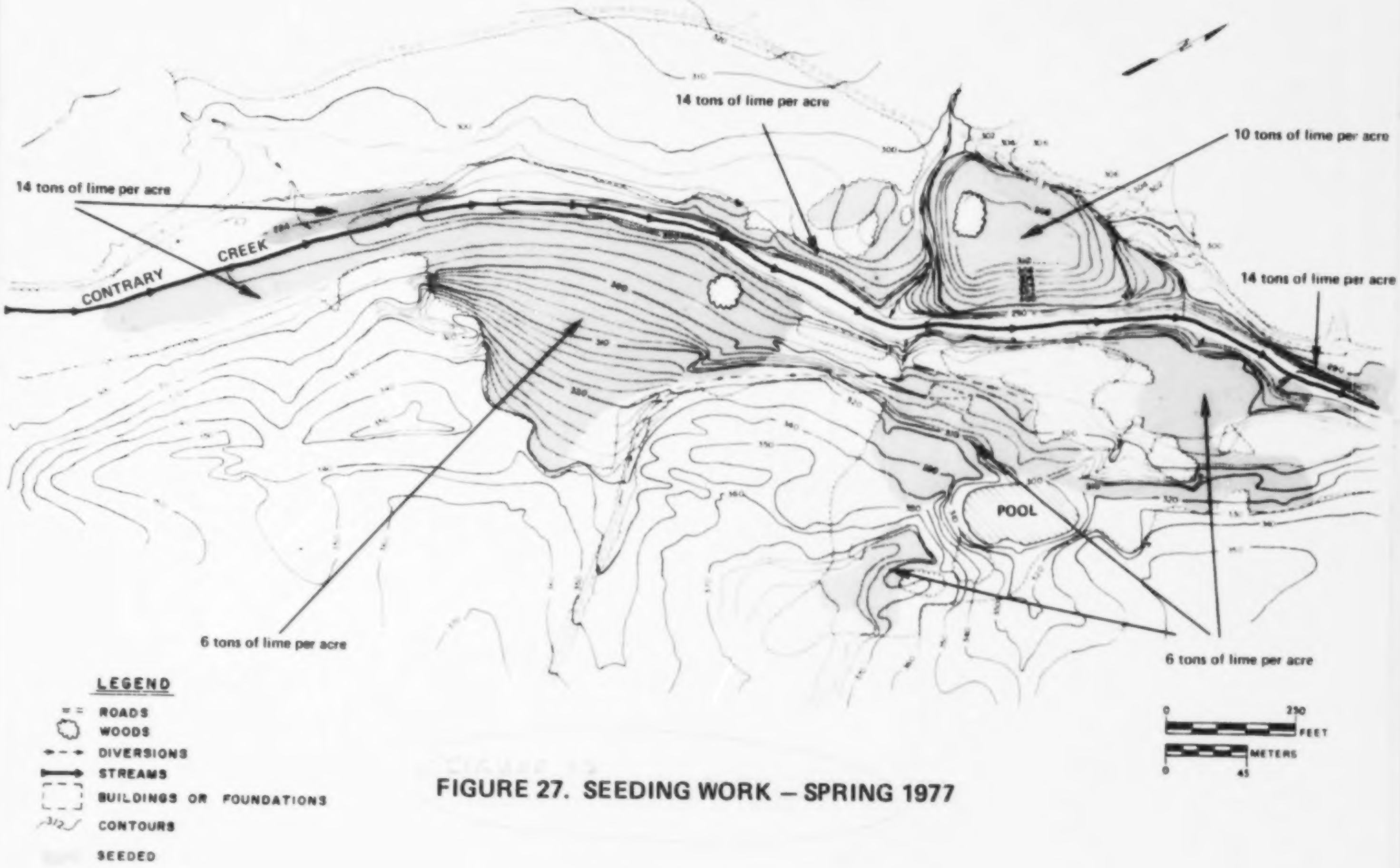


FIGURE 27. SEEDING WORK – SPRING 1977

fertilizers may have had. All remaining portions of both sites were treated with 10-10-10 fertilizer with the 38-0-0 ureaform again added to the severe areas where sludge had not been applied. A summary of fertilizer and application rates is given in Table 14.

TABLE 14. FERTILIZER APPLICATION RATES SPRING 1977 (Kg/ha)[a]

	Type	Sludged Areas	Unsludged Areas
Sulphur Site	16-7-12	336.3	896.8
	18-18-6	336.3	896.8
	10-10-10	560.5	560.5
	38-0-0		484.4
Boyd Smith Site	16-7-12	336.3	
	18-6-6	336.3	
	10-10-10	560.5	

[a] To convert Kg/ha to lbs/ac multiply by 0.892.

The seedbed was prepared with a small disc drawn by a farm tractor and a cultipacker was again used to incorporate seed. Weeping lovegrass and Korean lespedeza were added to the seed formula that had been used the previous summer. Seed types and application rates are shown in Table 15.

TABLE 15. SEEDING - SPRING 1977

Type	Kg/ha
Tall Fescue	67.3
Red top	5.6
Ladino Clover	2.2
Korean Lespedeza	11.2
Weeping Lovegrass	2.2

[a] To convert Kg/ha to lbs/ac multiply by 0.892.

In fulfillment of the original contract agreement the contractor planted 6500 pine seedlings of the species Virginia Pine (pinus virginiana) at the Boyd Smith Site. The Glatfelter Pulp Wood Company planted 17,000 Loblolly Pine seedlings at the Sulphur Site after seeding work was completed. In addition to the seeding and planting work a small section of riprap was placed on the North End of Sulphur East where Tr-2 enters Contrary Creek.

Under the contract modification with Sellers Brothers, Inc. all of the seeding work was done at both sites at a cost of $1,000 per acre which included the furnishing and planting of pine seedlings at the Boyd Smith Site. The only other cost item involving the work Sellers Brothers performed was equipment rental for a loader to place riprap. All mobilization costs were included in each cost item. Stone was again furnished and hauled to the site under a separate contract with A. H. Smith Stone. A cost breakdown appears in Table 16.

TABLE 16. MAINTENANCE COSTS - SPRING 1977

Seeding and Construction (Sellers Brothers, Inc.)		
Seeding 13.5 acres of Sulphur Site @ $1,000/ac		$13,500.00
Seeding 5 acres at the Boyd Smith Site @ $1,000/ac		5,000.00
44.5 hours of crawler tractor time @ $36/hr		1,602.00
	Subtotal	$20,102.00
Stone (A. H. Smith Stone)		
75.28 tons of riprap @ $7.50/ton		$564.60
45.14 tons of bedding @ $3.15/ton		142.19
	Subtotal	$706.79
	Grand Total	$20,808.79

The spring of 1977 reseeding work was almost a complete failure primarily due to the severe drought which followed. Rainfall for the months of June thru September was 22 centimeters below normal (Page 7) and by late summer some of the upper reaches of Contrary Creek, itself, had completely ceased flowing. The extreme drought not only negated the spring seeding but also destroyed some of the meager patches of Ky-31 grass that had survived from the previous summer. The one encouraging note was the weeping lovegrass which came on in late July at the height of the drought. This drought-tolerant grass which had been sown for the first time in the spring of 1977 exhibited a vigorous growth on most of the Large Area of Sulphur East and the Boyd Smith Site. The lovegrass was most successful in the same general areas that scattered patches of Ky-31 had managed to take root in 1976. The lovegrass was the only vegetation from the spring seeding that survived the summer, and it shows good survival after three years. Sulphur West remained practically barren as well as several other smaller areas of Sulphur East. Virtually all of the pine seedlings that had been planted at both sites died before the end of summer and most died within two weeks after planting. It was obvious by mid-summer that a major reseeding program would be necessary in the fall.

FALL 1977

With assistance from the SCS the SWCB prepared plans and specifications for the fall of 1977 maintenance work and arranged with the Blue Plains Wastewater Treatment Plant for delivery of additional sludge. The maintenance work consisted of (1) spreading and incorporation of sludge on designated areas; (2) liming, seeding, and mulching portions of both sites; and (3) modification of an existing beaver dam for a source of irrigation water at the Sulphur Site. Plans and specifications for the work were submitted to two local contractors who were asked to submit bids. The contract was awarded to W. C. Taylor of Mineral. The contractor did not submit the low bid, but the other bidder could not guarantee completion of the work within the prescribed time schedule. W. C. Taylor has done the major portion of all subsequent maintenance on a sole source non-bid basis.

All maintenance work was done during September and October. Seeding work was to be finished by the end of September, but a delay in the delivery of sludge forced completion of seeding to mid-October.

Sludge was applied only to the Sulphur Site. Approximately 1770 tonnes (wet weight) of sludge was applied to 1.1 hectares on Sulphur West and to 0.5 hectare on Sulphur East (Figure 28) which amounted to approximately 220 dry tonnes per hectare (99 tons/ac). Sludge was applied to the Upstream Flat of Sulphur East for the first time. This area where the stream had been straightened was too soft to support heavy epuipment when the 1976 work was done, but the extremely dry conditions of 1977 allowed the sludge trucks to dump directly on the areas of application. The sludge was again spread with a bulldozer and worked in with a heavy duty disc. The sludged areas were further smoothed by a small disc which was also used to prepare the unsludged areas for seeding (Figure 29).

The only area limed at this time was the Tailing Area of Sulphur West. Lime was applied at the rate of 22 tonnes per hectare (10 tons/ac). At the recommendation of the EPA Project Officer approximately 0.2 hectare had the lime sandwiched between two applications of sludge (Figure 28). After sludge and lime had been applied, seed was incorporated with a grain drill drawn by a farm tractor (Figure 30). This method of seeding was used for all subsequent maintenance except for inaccessible areas that were hand seeded. The same types of seed and application rates were used as in the spring of 1977 seeding with the exception of ladino clover which was dropped from the formula. A total of 3 hectares was reseeded at the Sulphur Site as shown in Figure 28. Mulch comprised of small grain straw was hand spread on approximately 2 hectares of newly seeded areas of the Sulphur Site and tied down by discing. The only work done at the Boyd Smith Site was the reseeding of approximately 0.2 hectare as indicated in Figure 31 using the same seed types and application rates.

Prior to application of sludge and the seeding work an existing impoundment which had been formed by a beaver dam was modified slightly for a source of irrigation water. This impoundment is approximately 200 meters upstream of Tr-1 from Sulphur West and contains good quality water. Since the dry

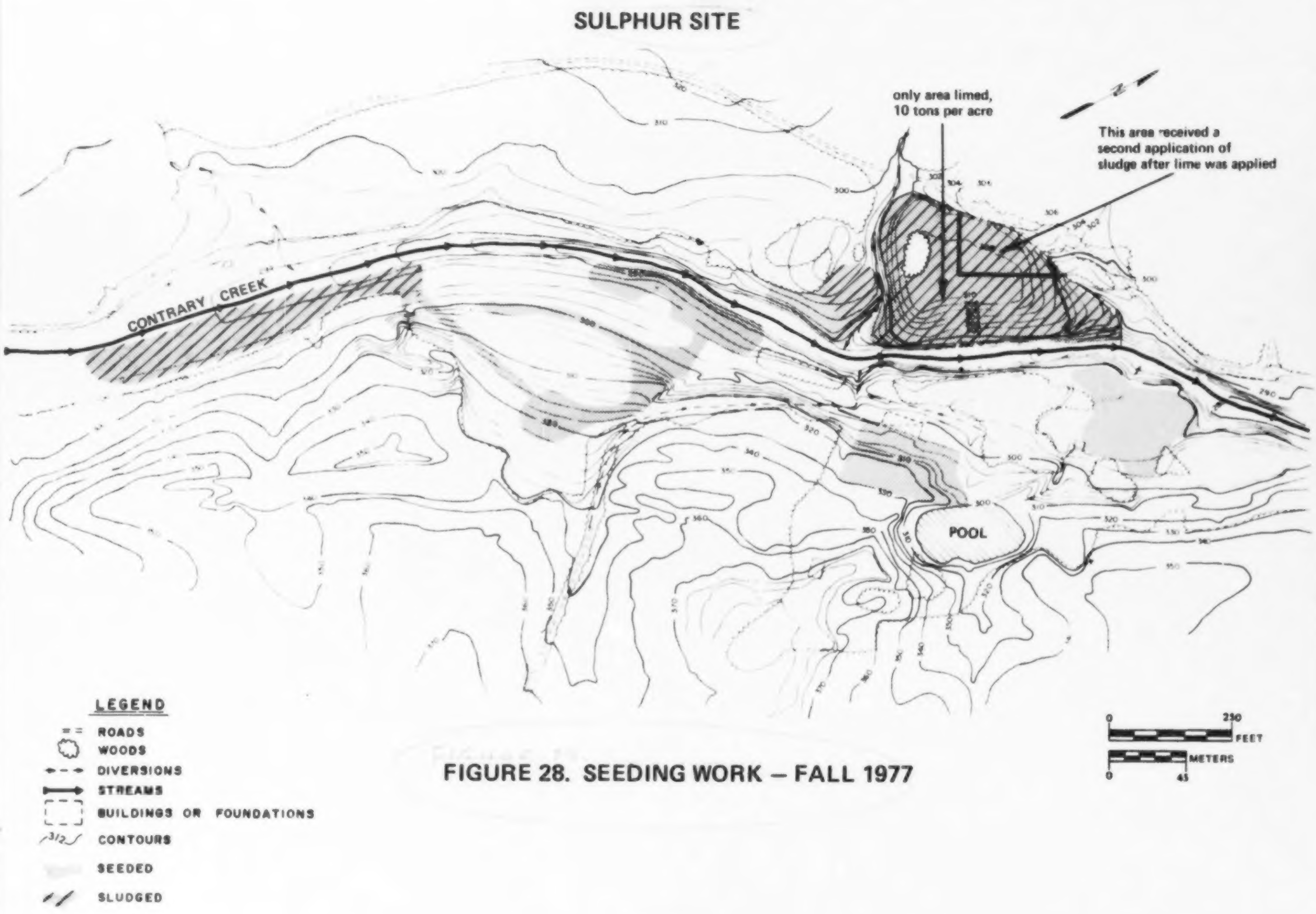


FIGURE 28. SEEDING WORK – FALL 1977

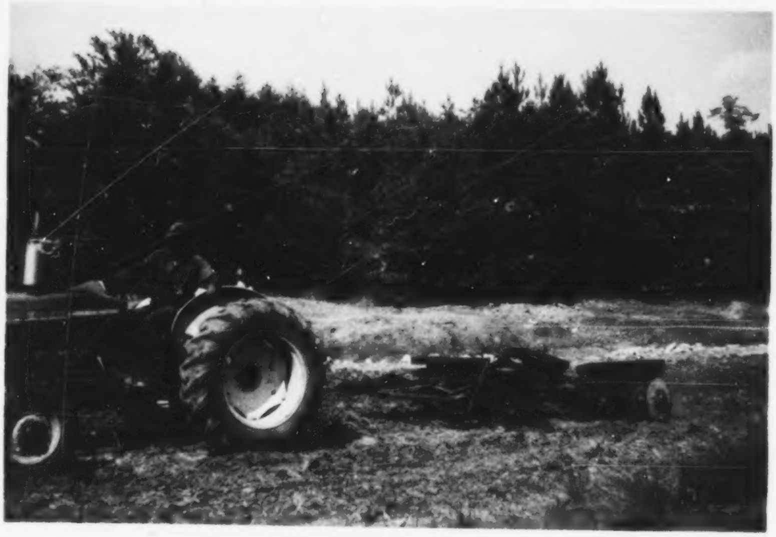


Figure 29. Preparation of seedbed with small disc.

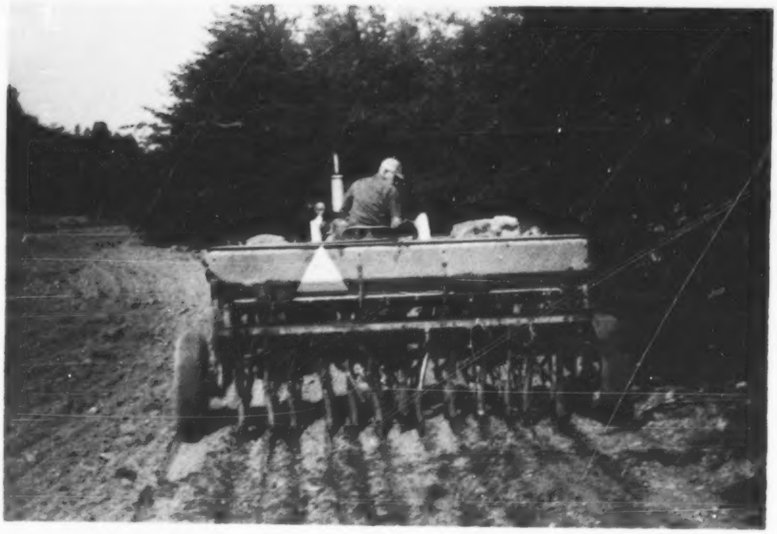


Figure 30. Seeding with a grain drill.

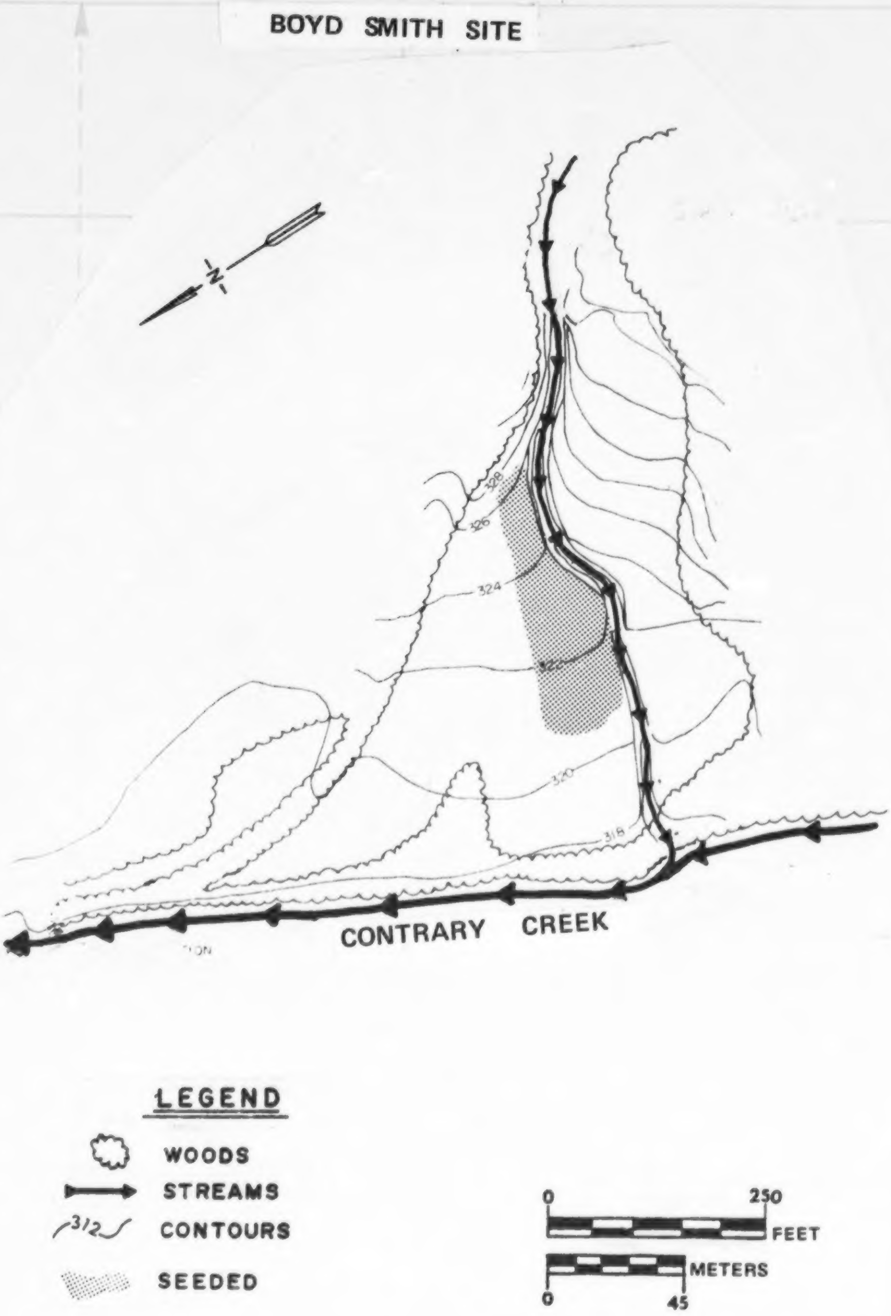


FIGURE 31. SEEDING WORK – FALL 1977

weather had continued up to the time of seeding, arrangements were made with another local contractor to provide equipment and apply irrigation water as needed. However, heavy rains in early November broke the drought, and it was not necessary to irrigate at this time.

Under the terms of the contract, payment for the spreading of sludge and the modification of the existing impoundment was on a lump sum basis. Payment for seeding which included furnishing all lime, seed, mulch, equipment, and labor was at the rate of $740 per acre. Another contract was later arranged with the same contractor to place some additional straw bales at the Sulphur Site for erosion control. A summary of costs appears in Table 17.

TABLE 17. MAINTENANCE COSTS - FALL 1977

Spreading 2,000 tons of sludge	$1300
Seeding 8.1 acres @ $740/ac	4957
Modification of impoundment	400
Placing 56 straw bales @ $4.50/bale	252
Total	$6909

The results of the 1977 fall seeding were the most encouraging so far for the project. The heavy rains during the first week of November caused grass to germinate in places that no germination had occurred before. The heavy application of sludge on the Upstream Flat of Sulphur East and the Tailing Area of Sulphur West was undoubtedly also a major factor. Particularly noteworthy was the Tailing Area of Sulphur West. Unfortunately, with the onset of cold temperatures so near, the grass did not have a chance to get a good start.

Despite the successes, some of the same old troublesome areas at the Sulphur Site remained bare or showed meager growth of grass. It was obvious that more spot seeding would be necessary the following year.

SPRING 1978

During the winter of 1978 soil samples were collected from the barren areas at the Sulphur Site to determine lime requirements. Results are discussed in Section 9. With the assistance of the SCS it was determined that approximately 1.6 hectares of the Sulphur Site would be reseeded during the spring season. It was decided that seeding work would not be attempted on the stream banks where the ground was very soft and because a major reseeding program was planned for the fall of 1978. While there was risk that another severe drought would make this work futile, it was felt that gains could be made if a more normal season of rainfall followed. The same contractor who had done the fall of 1977 work did the seeding; seed types and application rates are shown in Table 18. Note that red top was dropped from the seed formula. Figure 32 depicts the areas seeded.

TABLE 18. SEEDING - SPRING 1978

Species	Kg/ha[a]
Tall Fescue	67.3
Korean Lespedeza	11.2
Weeping Lovegrass	2.2

[a] To convert Kg/ha to lbs/ac multiply by 0.892.

A second contract was negotiated with a local supplier to furnish and spread lime over the reseeded areas at the rate of 22.25 tonnes per hectare (10 tons/ac), and a third contract was negotiated with another contractor to furnish and spread straw mulch over approximately 0.6 hectare of the Upstream Flat of Sulphur East. All liming and seeding work was done in early May and mulching was completed by mid-May. The seeding contract provided for the furnishing of all seed, equipment, and labor at a cost of $106 per acre. SCS officials certified that a total of 1.66 hectares was seeded. Table 19 gives a summary of costs.

TABLE 19. MAINTENANCE COSTS - SPRING 1978

Seeding 4.1 acres @ $106/ac	$434.60
38.42 tons of lime @ $14/ton	537.88
Mulching 1.5 acres	250.00
Total	$1222.48

A more normal season of rainfall during the summer of 1978 made the spring seeding quite successful. For the small amount of money spent on the spring seeding the returns were great, but some of the same problem areas persisted along the stream banks at the Sulphur Site. As indicated above no attempt had been made to reseed some of the wetter areas at this time. One of the more encouraging signs was the increasing grass cover that was apparently establishing on the Tailing Area of Sulphur West. The Ky-31 grass was still showing a vigorous growth and for the first time Korean lespedeza germinated. Also numerous volunteer weeds began to invade the Large Area of Sulphur East and the Boyd Smith Site. By this time it appeared that the Boyd Smith Site would require little additional seeding. The weeping lovegrass again made a good showing during the hot summer months, and it did very well in the Upstream Flat of Sulphur East where little other vegetation had ever germinated.

SULPHUR SITE

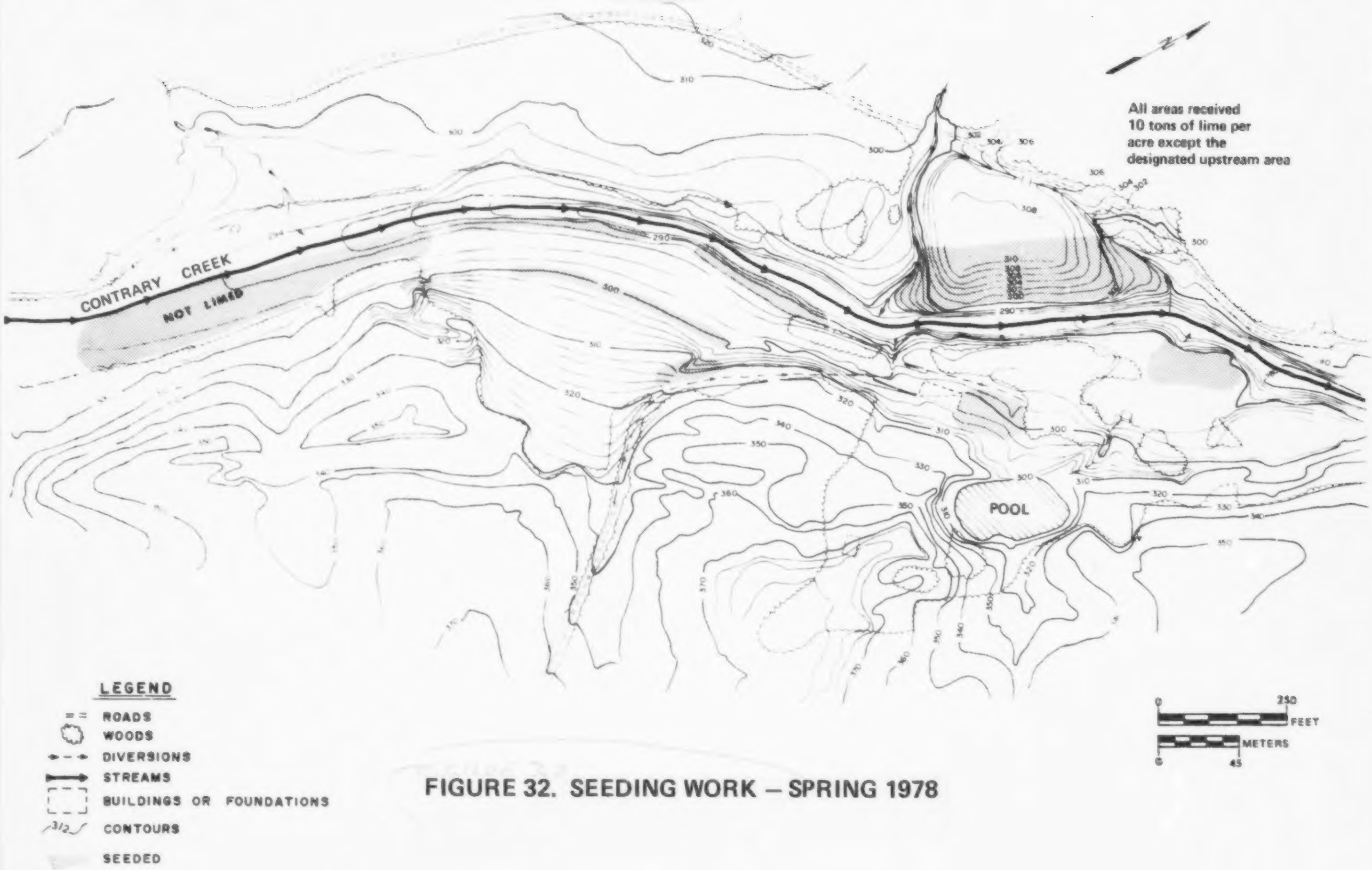


FIGURE 32. SEEDING WORK – SPRING 1978

FALL 1978

Plans were underway early in the summer of 1978 for the fall maintenance. Additional soil samples were collected in the problem areas to determine lime requirements and arrangements were made with the Blue Plains Sewage Treatment Plant for delivery of more sludge. At the recommendation of the SCS plans were made to place some additional riprap at the Sulphur Site. The contract provided for all maintenance including (1) construction of berms to retain sludge, (2) spreading sludge, (3) seeding, (4) riprap work, and (5) placing additional straw bales.

Delivery of sludge began in late July and was completed in August. A total of 540 tonnes was stockpiled at three locations on the Sulphur Site. This was the first time that sludge was stockpiled for any appreciable time before application. The reason was primarily because most of the application areas were inaccessible to the sludge trucks. Sludge handles much better the longer it dries, but there is of course extra work involved in transporting it from stockpiles to areas of application and there is some risk of heavy rain washing it out of stockpile areas.

Spreading of lime and sludge began in mid-September. Lime was applied with a spreader truck (Figure 33) at rates ranging from 11 to 33 tonnes per hectare (5 to 15 tons/ac) as shown in Figure 35. Sludge was hauled from stockpiles with an earthmoving pan and partially spread as it was released from the pan (Figure 34). Further smoothing was done with a bulldozer before sludge was disced in. Approximately 0.8 hectare or about one acre on each side of the Sulphur Site was sludged (Figure 35) with approximately 138 dry tonnes per hectare (60 tons/ac).

The seedbed of the unsludged areas was prepared with a small disc and seeding was again done with a grain drill. The same seed formula was used as the previous spring except that rye was planted at the rate of 22 kilograms per hectare (20 lbs/ac) for a nurse crop.

All seeding work was completed during September, and straw mulch at the rate of 4.45 tonnes per hectare (2 tons/ac) was placed by hand on all newly seeded spots. A total of 1.62 hectares was seeded.

A 50-meter section of riprap was placed on the east side of Contrary Creek along the Upstream Flat where inflow from a tributary from the opposite side was beginning to erode the stream bank. Another small section of riprap with bedding was placed in a gully that was starting to develop in the Tailing Area of Sulphur West. Riprap sections are shown in Figure 18. Forty-seven new straw bales were placed for continued erosion control.

After the seeding was completed, a small amount of rainfall in early October germinated the new seed, but another dry spell followed and threatened the survival of the new grass. It was quickly decided to irrigate all the seeded areas feasible. The beaver pond that had been modified for this purpose a year earlier was still intact, and the same contractor that had agreed to do this work the previous year was hired to irrigate all of the areas accessible to piping. Water was pumped from the impoundment west of the

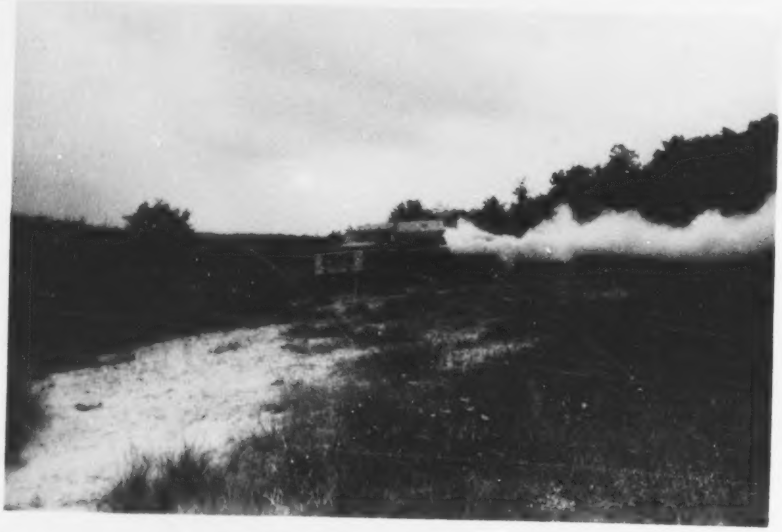


Figure 33. Lime spread by truck on Sulphur East.

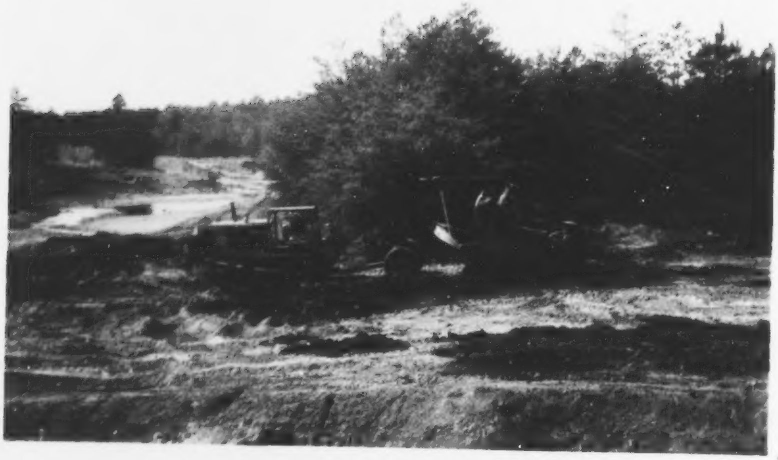


Figure 34. Sludge spread by earthmoving pan on Tr-1 of Sulphur West.

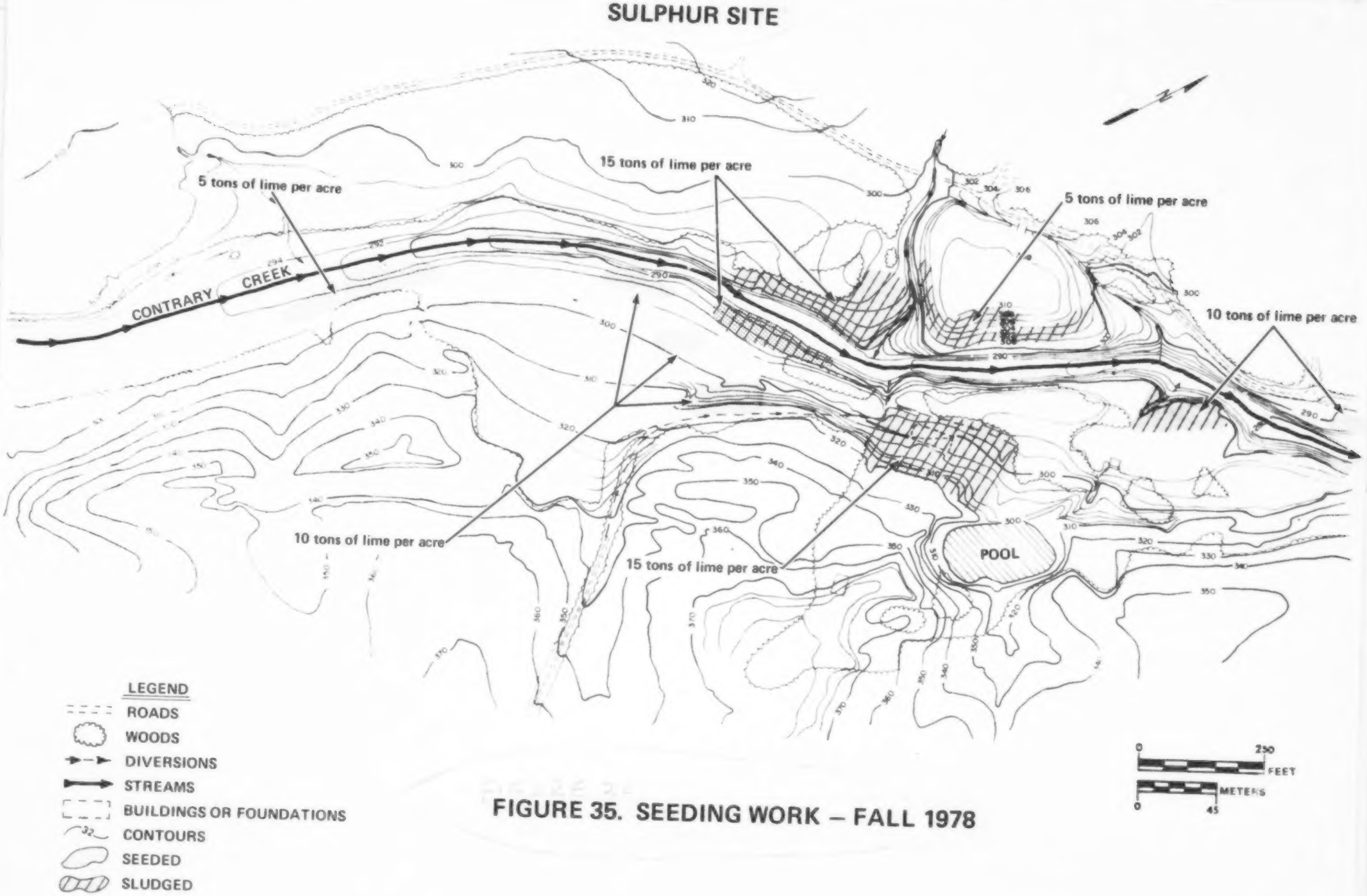


FIGURE 35. SEEDING WORK – FALL 1978

Sulphur Site and sprayed by a system of 30 sprinklers. Between October 23 and November 13 water was applied to about 1 hectare on 5 different occasions. Approximately 2.54 cm of water was applied each time. All of the newly seeded areas were irrigated except the Upstream Flat and the North End of Sulphur East.

Payment was by the acre for seeding including lime, seed, mulch, equipment, and labor. The contractor was paid for an additional 5.875 tons of lime required above the contract estimate. Payment for riprap was by the ton for furnishing and placing stone. Payment for placing straw bales was by the bale and payment for construction of berms to retain sludge was on a lump sum basis. The total cost of the irrigation work was $325 which included $150 for setting up equipment and $35 per application. Itemized costs for the Fall of 1978 maintenance appear in Table 20.

TABLE 20. MAINTENANCE COSTS - FALL 1978

Construction of berms to retain sludge	$200.00
Spreading and discing in sludge	3000.00
Seeding 4 acres @ $740/ac	2960.00
5.875 tons of additional lime @ $15/ton	88.12
100.39 tons of riprap @ $9/ton	903.51
18.82 tons of bedding @ $7/ton	131.74
47 straw bales @ $2.25/bale	105.75
Setup of irrigation equipment	150.00
5 applications of irrigation @ $35/application	175.00
Total	$7714.12

The results of the fall irrigation work were most beneficial. Grass germinated on some portions of the stream banks of Sulphur East and Sulphur West where no grass had ever sprouted before. The Ky-31 fescue which is a cool weather grass showed the most success. It was again obvious that the sludge was a major factor in promoting the growth of vegetation. Some of the same old problem areas remained barren despite the success of the fall seeding indicating need for continued maintenance.

SPRING 1979

The maintenance program was continued in the spring of 1979 with spot seeding and application of lime and fertilizer. A total of 0.85 hectare was seeded at the Sulphur Site the last week of April. Seed species and rates are given in Table 21 and seeded areas are designated in Figure 36. Wheat straw was hand spread over all seeded areas for mulch.

TABLE 21. SEEDING - SPRING 1979

Species	Kg/ha[a]
Tall Fescue	67.3
Korean Lespedeza	11.2
Sericea Lespedeza	11.2
Weeping Lovegrass	2.2
Oats	35.9

[a] To convert Kg/ha to lbs/ac multiply by 0.892.

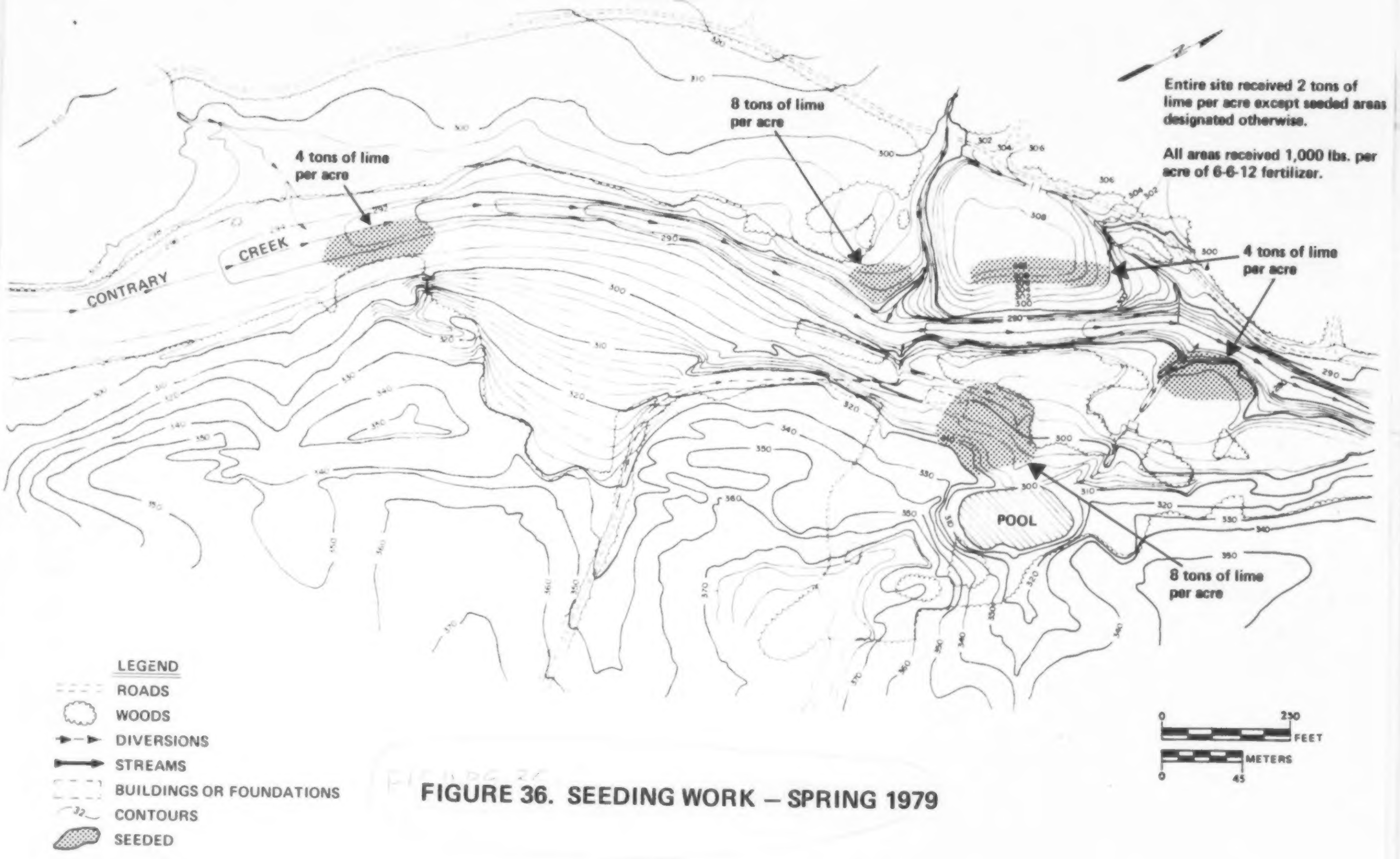
Because continued soil tests by the SCS had begun to suggest a strong association between bareness and potash deficiency, it was decided that a high potash fertilizer of the formula 6-6-12 would be used. In the initial reclamation work a high nitrate fertilizer of the formula 38-0-0 had been used. A total of 9.07 tonnes of 6-6-12 fertilizer was applied to all of the Sulphur and Boyd Smith Sites at the rate of 1121 kilograms per hectare (1000 lbs/ac).

Lime was applied at rates ranging from 8.9 tonnes per hectare (4 tons/ac) to 17.8 tonnes per hectare (8 tons/ac) on reseeded areas of the Sulphur Site as determined by soil tests (Figure 36). All remaining portions of both sites were limed at the rate of 4.45 tonnes per hectare (2 tons/ac). In areas inaccessible to a spreader truck, lime and fertilizer were spread by a tractor drawn whirlybird spinner or by hand (Figure 37). All lime and fertilizer application was done in May except for a few truckloads of lime delayed until early June by wet ground.

Other work done as part of the spring maintenance included reconstruction of a diversion at the Sulphur Site and placement of additional straw bales for erosion control. The contractor furnished all materials and labor and was paid at the rates shown in Table 22.

A continuing improvement in vegetative cover was apparent over most of the reclaimed areas during the summer of 1979. Notable areas of improvement resulting from the spring seeding were the Tipple Area of Sulphur East and in the vicinity of Tr-1 on both sides of the creek. Numerous varieties of weeds continued to invade the Large Area of Sulphur East along with at least two species of trees. Of the grasses sown, the Ky-31 fescue continued to be

SULPHUR SITE



Entire site received 2 tons of lime per acre except seeded areas designated otherwise.

All areas received 1,000 lbs. per acre of 6-6-12 fertilizer.

FIGURE 36. SEEDING WORK – SPRING 1979

the mainstay with the lovegrass making its usual good showing in mid-summer. Both varieties of lespedeza showed only moderate success. Parts of the Tailing Area of Sulphur West, the North End of Sulphur East and some of the stream banks still supported little or no vegetation and obviously remained highly toxic.

TABLE 22. MAINTENANCE COSTS - SPRING 1979

10 tons fertilizer @ $16.50/ton	$1165.00
46.46 tons lime @ $18/ton (truck spread)	836.28
9.7 tons lime @ $30/ton (hand spread)	291.00
2.1 acres seeded and mulched @ $395/ac	829.50
43 straw bales @ $2.50/bale	107.50
Regrading diversion (lump sum)	150.00
Total	$3379.28

Although precipatation was generally abundant throughout Virginia during most of 1979, only 1.88 centimeters of rain fell on the project site in July. When the dry weather threatened the survival of the new grass and began to take its toll on some of the established parts of Sulphur West, the SCS recommended irrigation at once. The same contractor who had done the fall of 1978 irrigation was hired, and five applications of water were made to critical areas during August (Figure 38). The irrigation along with more normal rainfall during late summer maintained much of the grass on Sulphur West that would probably have died. Cost of irrigation was as follows:

Setup of equipment	$225
5 applications @ $45/application	225
TOTAL	$450

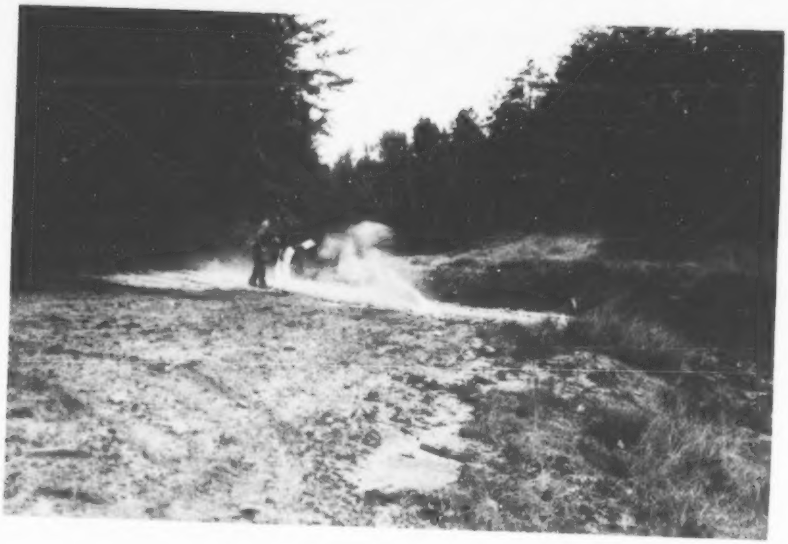


Figure 37. Spreading lime by hand at Boyd Smith Site.

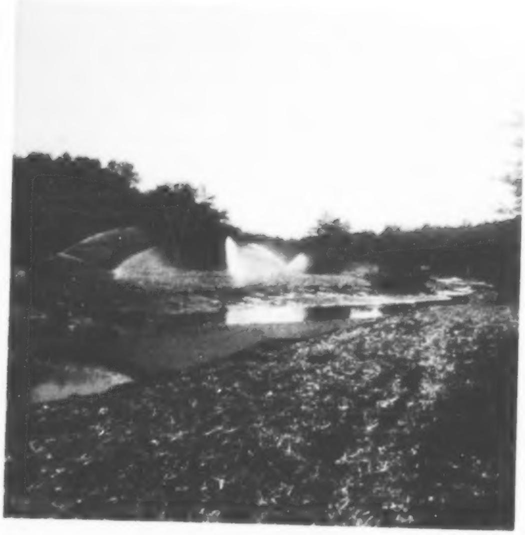


Figure 38. Irrigation of Sulphur Site.

FALL 1979

Essentially the same maintenance was performed in the fall as had been done in the spring except that sludge was again applied to some of the problem areas that persisted. A small portion of the Boyd Smith Site which had remained barren and had started to encroach upon established vegetation was reworked. No seeding had been done at this site since the fall of 1977. Lime and fertilizer were applied in early September to all of the Sulphur Site and that portion of Boyd Smith Site seeded as indicated in Table 23.

TABLE 23. LIME AND FERTILIZER APPLICATION - FALL 1979

Lime		tonnes/ha[a]
Sulphur East		
Upstream Flat		17.8
Large Area		8.9
Tipple Area		17.8
North End		17.8
Sulphur West		
Tailing Area		22.25
Tr-1		8.9
Boyd Smith		22.25
	Total	82.18
Fertilizer		
Formula		6-0-12
Rate		1121 Kg/ha[b]
Total		6.35 tonnes

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[a] To convert tonnes/ha to tons/ac multiply by 0.449.
[b] To convert Kg/ha to lbs/ac multiply by 0.892.

Approximately 308 tonnes of sludge were delivered from the Blue Plains STP and stockpiled at the Sulphur Site during August. After liming and fertilizing was complete, sludge was hauled with a dump truck to areas to be reseeded at each site and spread with a loader (Figures 39 and 40). Although this did not incorporate the sludge to the depth normally desired and in fact left much of it at the surface, it appeared that the seed germinated quite well. Also the limited amount of sludge used at this time minimized its possibility of being washed into the stream. An estimate of the rate per hectare over the widely scattered small areas is difficult to make, but based upon the 0.73 hectare seeded, it would be about 82 dry tonnes per hectare (37 tons/ac). Seeding and mulching was completed in early October and dilapidated straw bales were replaced. Seed species and rates are given in Table 24.

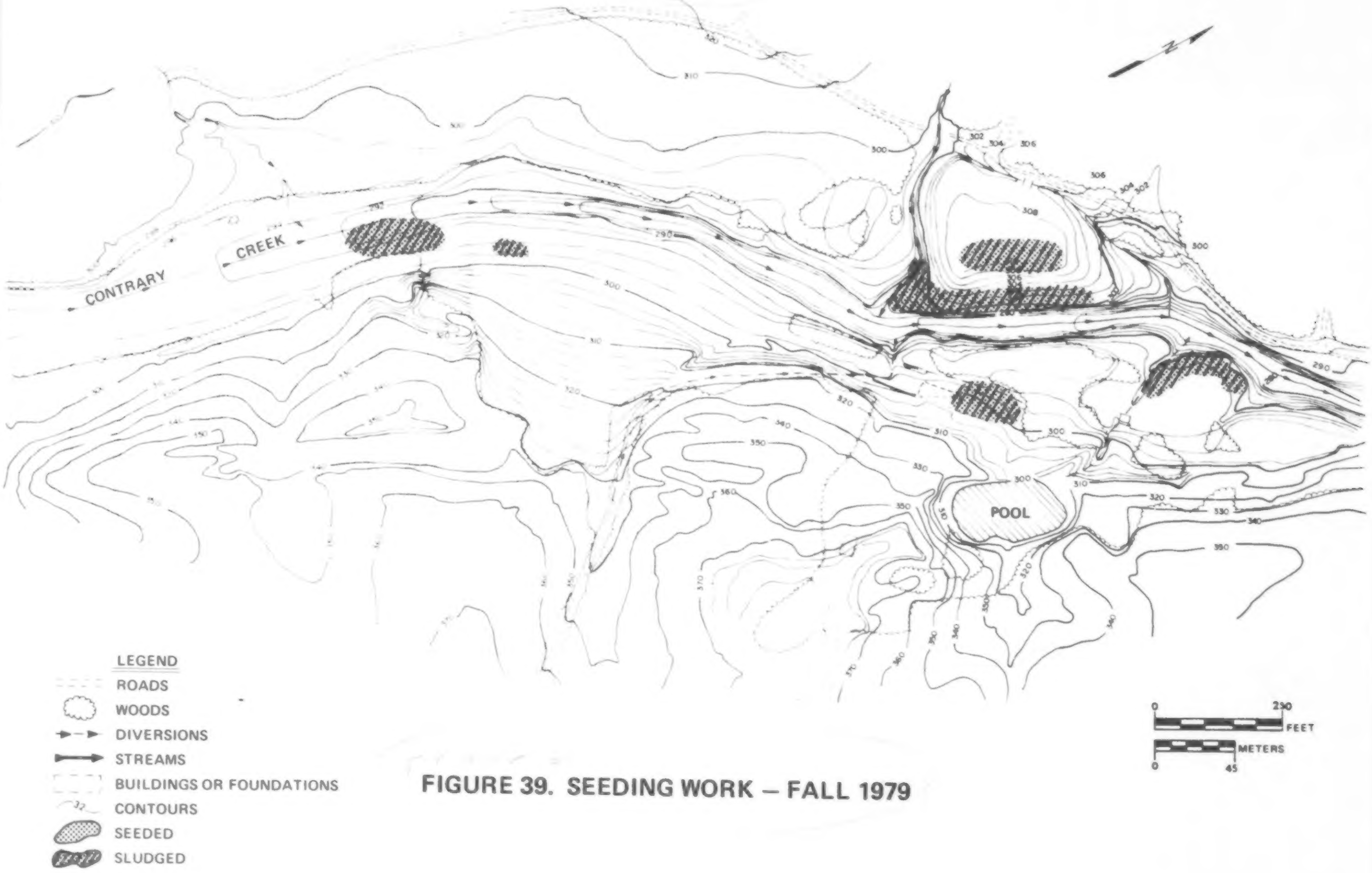

FIGURE 39. SEEDING WORK – FALL 1979

BOYD SMITH SITE

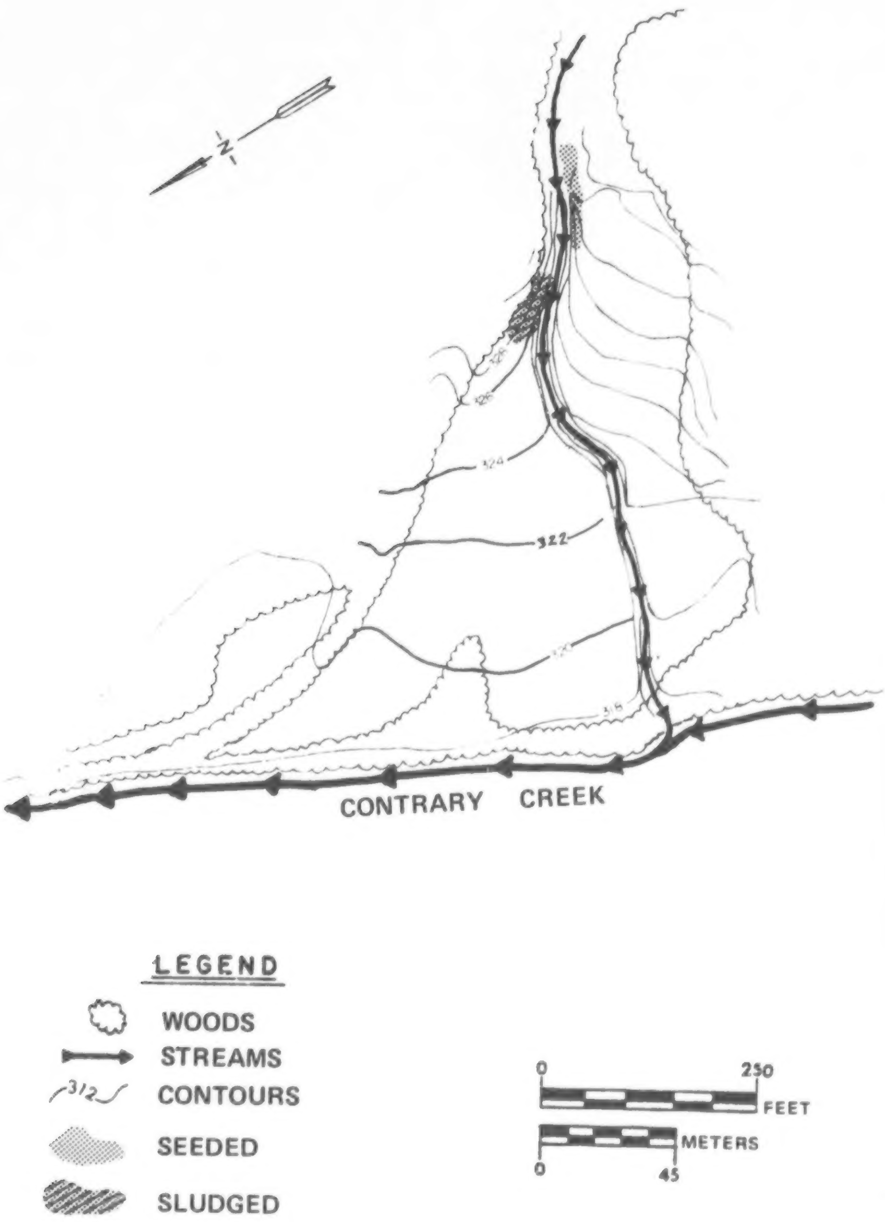

FIGURE 40. SEEDING WORK – FALL 1979

TABLE 24. SEEDING - FALL 1979

Species	Kg/ha[a]
Tall Fescue	67.3
"Tolerant" Red Fescue	11.2
Weeping Lovegrass	2.2
Wheat	67.3

[a] To convert Kg/ha to lbs/ac multiply by 0.892.

The "tolerant" red fescue was added to the seed formula because it had been used in the reclamation work at the Arminius Site and had appeared quite successful. At the recommendation of the SCS, no legume was included, but Korean lespedeza was hand sown over the same areas in February of 1980. Itemized costs of the maintenance work are presented in Table 25.

TABLE 25. MAINTENANCE COSTS - FALL 1979

88.6 tons lime @ $20/ton (truck spread)	$1772.00
2 tons lime @ $40/ton (hand spread)	80.00
7 tons fertilizer @ $116.50/ton	815.50
1.8 acres seeded @ $500/ac	900.00
Spreading sludge @ $45/hr	990.00
36 straw bales @ $2.50/bale	90.00
Repairing access road	40.00
Towing sludge truck	30.00
TOTAL	$4717.50

The fall of 1979 maintenance was one of the more successful endeavors in the project. By late fall the grass cover over the entire Sulphur Site looked as good as it ever had and new grass had sprouted on most of the reseeded areas. One notable area of pronounced improvement was the North End of Sulphur East. The continued use of sludge was undoubtedly a factor along with abundant rainfall in germinating the new grass and the high potash fertilizer may have begun to have some effect.

SPRING-FALL - 1980

Lime and fertilizer were again applied to all of the Sulphur and the north side of the Boyd Smith Site in April and September of 1980. On both occassions lime was applied at the rate of 8.9 tonnes per hectare (4 tons/ac) and fertilizer was applied at the rate of 1121 kilograms per hectare (1000 lbs/ac). Fertilizer of the type 6-0-12 was used in the spring work, but after soil tests in August showed a decline in phosphate availability, 6-6-12 fertilizer was again used in the fall maintenance.

Abundant rainfall during April and May promoted a vigorous growth of vegetation over most of the reclaimed areas, but the sudden onset of another drought in June necessitated resumption of irrigation. Six applications of irrigation during July were essential in preserving vegetation on critical portions of the Sulphur Site. The 1980 drought did minimal damage to the overall project, but prohibited any significant gains in establishing vegetative cover during this growing season. A summary of the 1980 maintenance costs is presented in Table 26. At the request of the SWCB in the summer of 1980, the EPA approved an extension of the project until 1982 to provide for furthur maintenance.

TABLE 26. MAINTENANCE COSTS -1980

Spring		
78.25 tons of lime @ $22/ ton		$1721.50
8 tons of fertilizer @ $16.50/ton		932.00
Hand seeding 30 lbs. lespedeza (lump sum)		33.00
	Subtotal	$2686.50
Summer		
Setup of irrigation equipment		$250.00
Six applications @ $60/application		360.00
	Subtotal	$610.00
Fall		
77.52 tons of lime @ $22/ton		$1705.44
8.5 tons of fertilizer @ $26.65/ton		1076.52
	Subtotal	$2781.96
	Grand Total	$6078.46

SECTION 8

ARMINIUS SITE RECLAMATION

In terms of size and disturbance of natural conditions, the Arminius Site was intermediate to the Boyd Smith and Sulphur Sites. Approximately 4 hectares were disturbed at this site. Tailings covered the denuded areas on both sides of Contrary Creek, but the natural topography was not altered significantly (Figures 41 and 42). For purposes of this report the part of Arminius Site on the east side of Contrary Creek shall be known as Arminius East and that on the west as Arminius West. Four old settling ponds remain on the north side of Arminius East (Figure 43).

As stated earlier in this report, Callahan Mining Corporation had agreed to reclaim this site and reclamation was expected to start more or less concurrently with the work at Boyd Smith and Sulphur. After there was some delay in initiating the work at Arminius, the SWCB issued a Consent Order to Callahan requiring that steps be taken to abate the AMD from the Arminius Site.

Callahan began work on Arminius West which consists of about 1.2 hectares in the fall of 1976 and work began on Arminius East in the spring of 1977 which involved approximately 2 hectares. No reclamation work was done on the old settling ponds at Arminius. All of the reclamation work at the Arminius Site has been under the direction of a private consultant who had begun test plot studies at that site in 1974 using various application rates of soil additives and seed types. The results of these experimental test plots are discussed in Appendix D. The original reclamation work and postreclamation maintenance was performed by local contractors and a major portion of the work was performed by the same contractor that did the maintenance work at the Sulphur and Boyd Smith Sites.

The reclamation measures implemented at the Arminius Site have been essentially the same as those used at the other two sites downstream with the exception of some variation in application rates of soil additives and seed types. As at the Sulphur and Boyd Smith Sites, spoil areas were regraded, stream banks riprapped, and soil additives were applied including lime, fertilizer and wastewater sludge. Sludge for this site was hauled from the same source, the Blue Plains STP in Washington, D.C. Sludge was applied at a considerably lower rate per hectare and lime application rates varied from those used at the Boyd Smith and Sulphur. Only a few small portions of the site were fertilized.

The results of the reclamation work at the Arminius Site have been very similar to that at Boyd Smith and Sulphur. The drought of 1977 of course had its harsh effects on this site too, and there were some very toxic areas to be

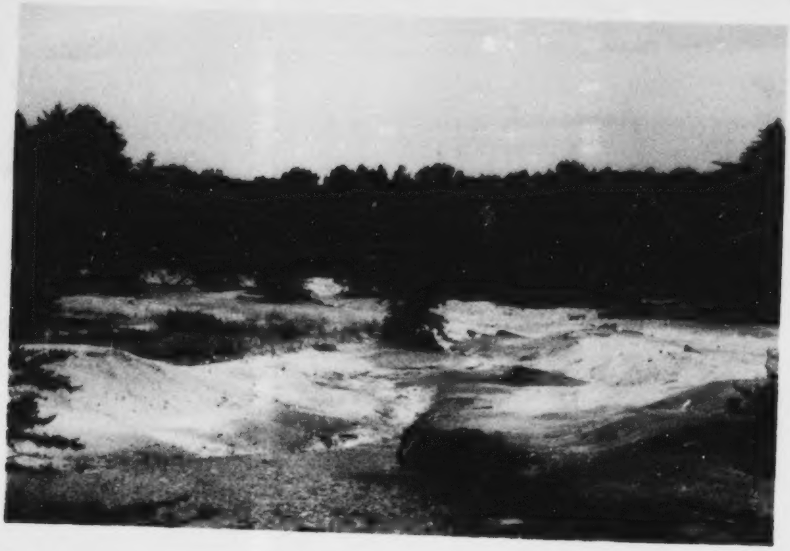

Figure 41. Barren areas of Arminius East prior to reclamation.

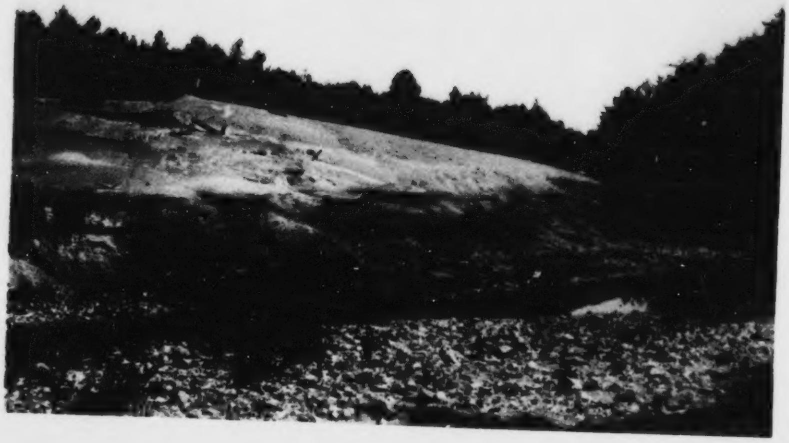

Figure 42. Mine tailings along Contrary Creek at Arminius West prior to reclamation.

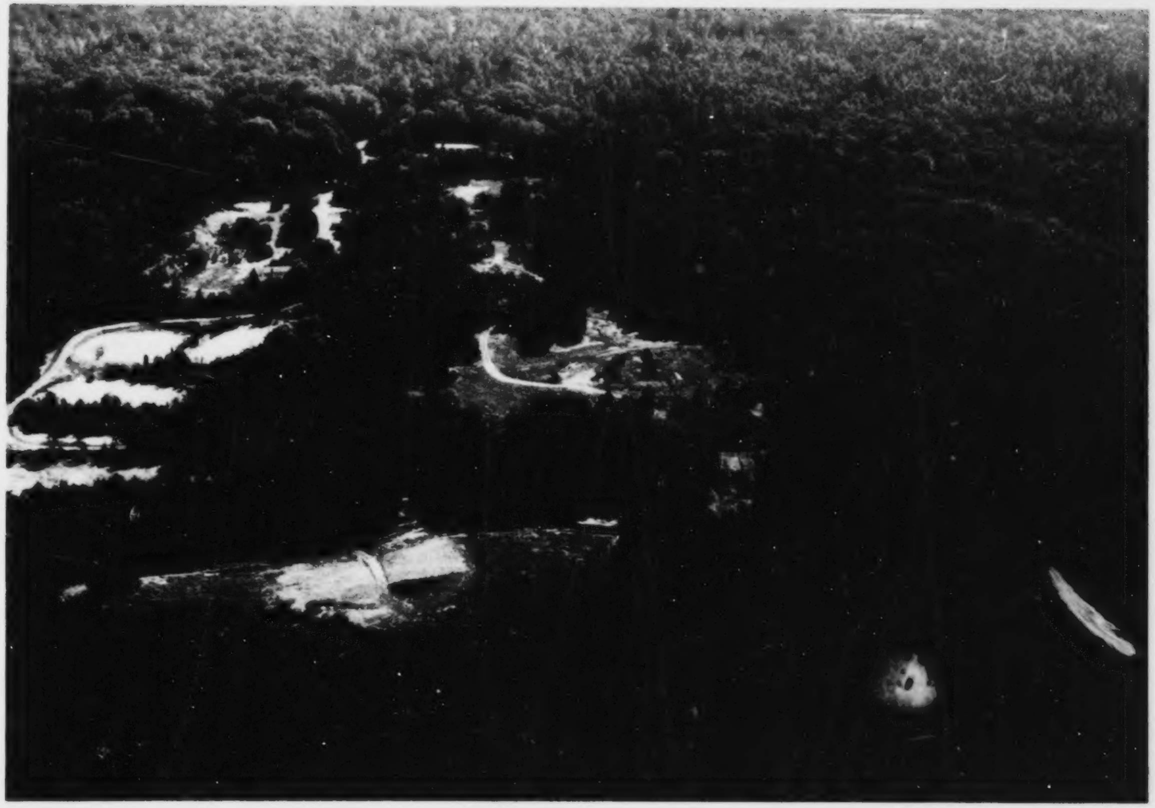

Figure 43. Arminius Site after reclamation-Fall 1978.

dealt with here as at the Sulphur Site. A maintenance program consisting of spring and fall seeding similar to that at Boyd Smith and Sulphur along with application of additional lime and sludge and placement of riprap for erosion control has been carried out at this site. By late 1980 most of the reclaimed areas had a fairly good cover of vegetation including some of the same grass species used at the other two sites along with other plantings which have been quite successful. However, the hot dry summer of 1980 seriously affected some parts of this site and it is likely that some further reseeding will be necessary. It is anticipated that a detailed report of the reclamation at this site will be prepared by the consultant for Callahan Mining Corporation.

SECTION 9

POSTRECLAMATION CONDITIONS

This section presents an evaluation of postreclamation conditions at the project site from the standpoint of vegetative cover, erosion control, soil analyses, water quality, and biologic studies. Vegetative cover has been evaluated by periodic inspections by SCS and SWCB personnel along with aerial photography by the VDH&T. The SCS used the universal soil loss equation to estimate degree that erosion had been reduced, and soil tests have been conducted regularly by the SCS and SWCB. All water quality data except a special study by the University of Virginia have been generated by a comprehensive monitoring program still being conducted by the SWCB. Biologic studies have been conducted by the SWCB and are still in progress.

VEGETATIVE COVER

As related in Sections 6 and 7 the establishment of vegetation on the reclaimed mine sites has been slow and difficult, especially at the Sulphur Site, and the droughts of 1976 and 1977 could not have come at a less opportune time. There was really no appreciable success until the summer of 1978. Another dry summer in 1980 continued to hinder vegetative growth.

The aerial photos in Figures 44 - 47 compare conditions at both sites before reclamation started and in the summer of 1980. The photos show that the potential for erosion was reduced considerably. A general evaluation of conditions in late 1980 is presented in Table 27. The Boyd Smith Site (Figures 48 and 49) supports the most dense grass mat of any of the SWCB reclaimed areas and the Large Area of Sulphur East had the most diverse vegetation (Figures 50 and 51). The more difficult areas have been the Tailing Area of Sulphur West (Figures 52 and 53), the North End of Sulphur East, and the stream banks at that site.

The Ky-31 fescue grass has been the mainstay of the vegetation. This cool-weather grass has established quite well over about 75 per cent of the Sulphur Site (Figure 54) and covers better than 90 per cent of the Boyd Smith Site. As would be expected it makes its best showing in the spring and fall, but becomes dormant during hot dry weather and begins to die out if prolonged drought occurs. However, it usually greened up within a few days after substantial rainfall or when irrigation was applied. The ability of the fescue to reach maturity and reseed itself has undoubtedly contributed to its success on the reclaimed mine sites.

The second most successful species has been the weeping lovegrass which is drought tolerant and has proven invaluable during the dry weather that has plagued the project. During the summer of 1977, the first year it was planted,

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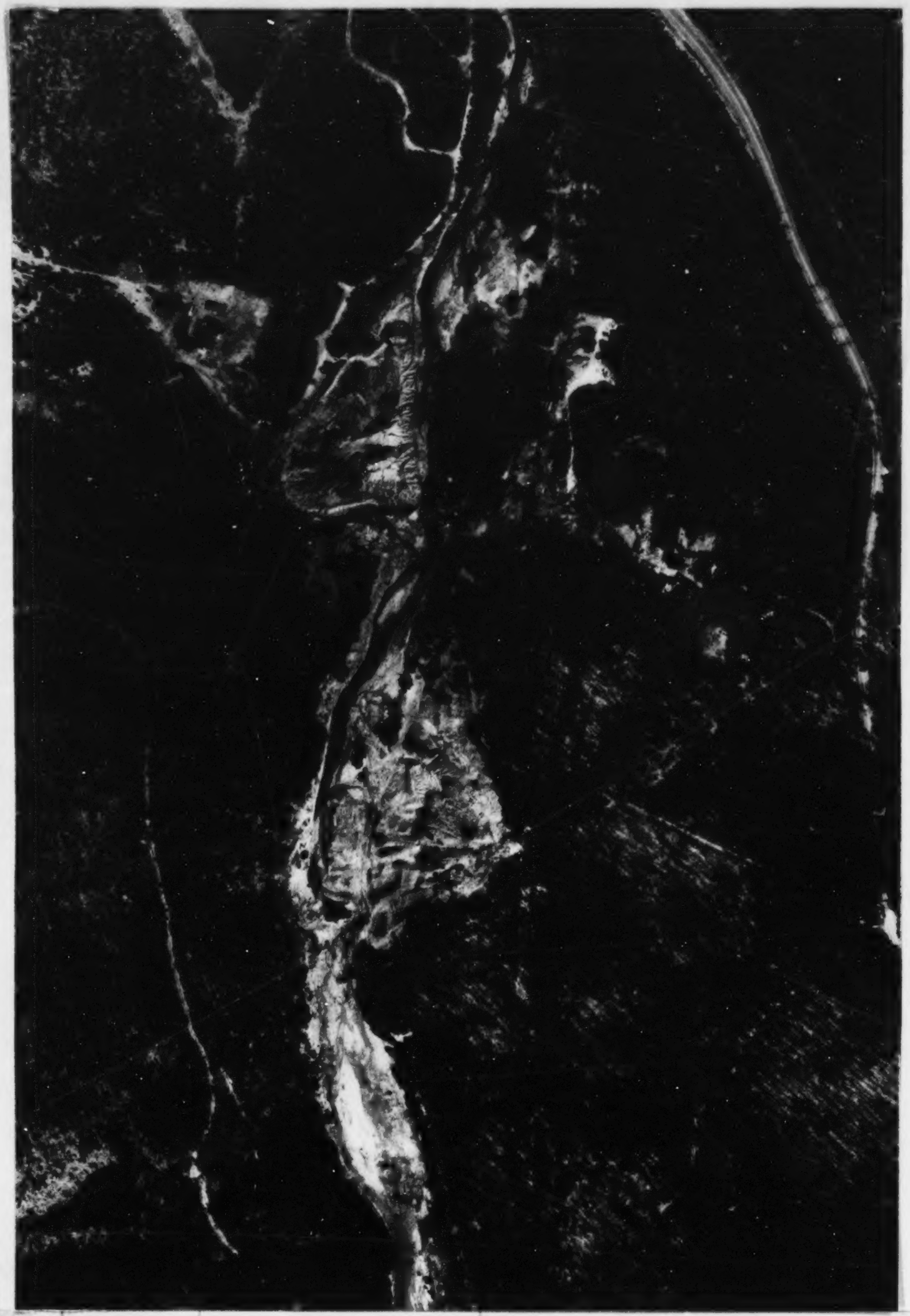

FIGURE 44. SULPHUR SITE – BEFORE RECLAMATION

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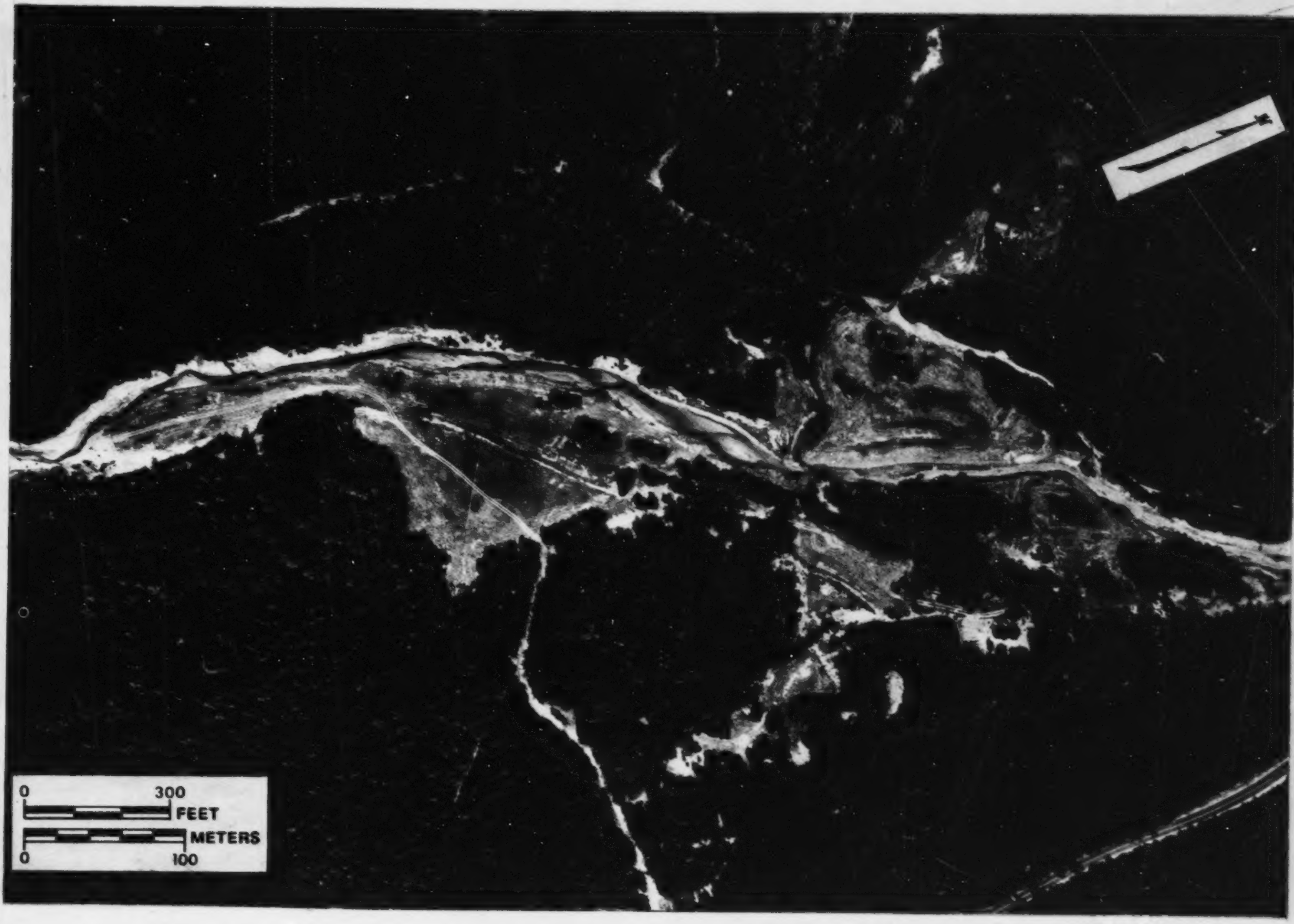

FIGURE 45. SULPHUR SITE IN 1980

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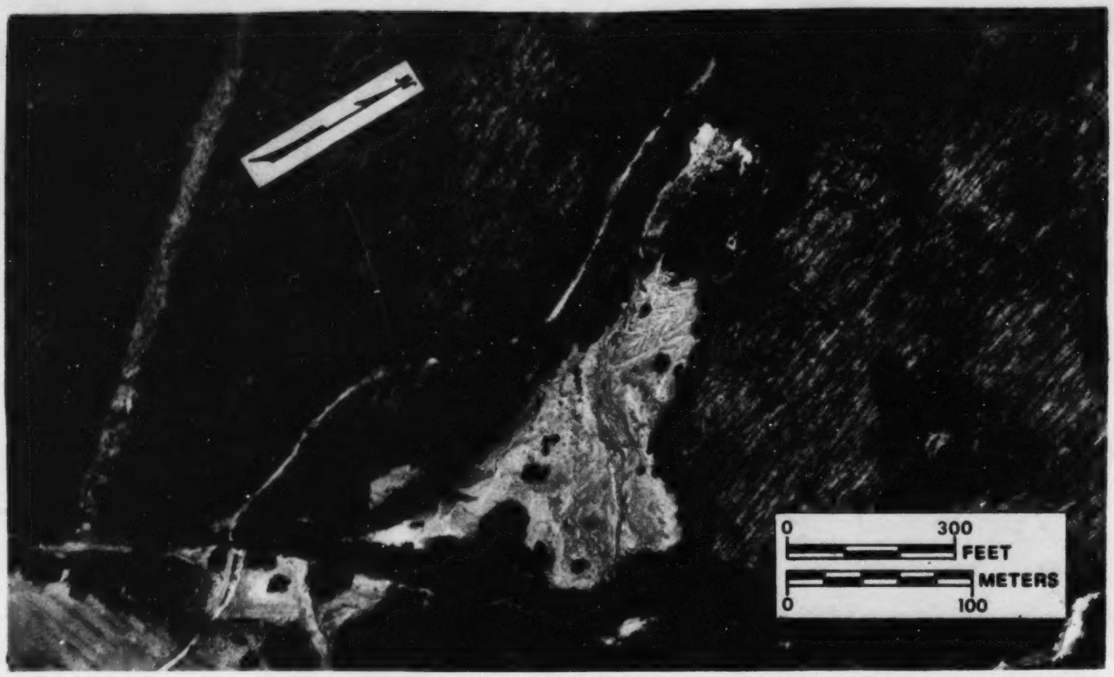

FIGURE 46. BOYD SMITH SITE-BEFORE RECLAMATION

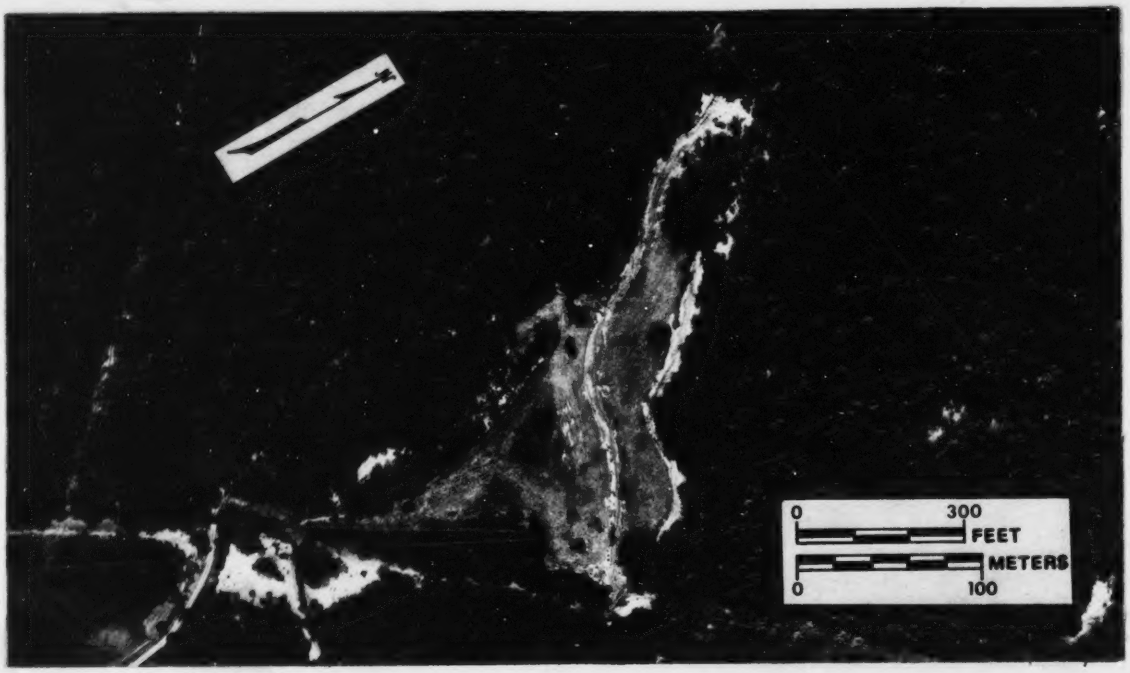

FIGURE 47. BOYD SMITH SITE IN 1980

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TABLE 27. EVALUATION OF VEGETATIVE COVER IN LATE 1980

Work Area	Size (ha)[a]	Per Cent of Grass Cover	General Conditions
Sulphur East			
Upstream Flat	0.55	90	moderate cover, weeping lovegrass dominant, some areas difficult to establish because of poor drainage
Large Area	2.20	95	good cover except along stream banks, Ky-31 dominant, numerous varieties of weeds and some trees invading
Tipple Area	0.75	90	moderate cover, improved during 1979 and 1980, Ky-31 dominant
North End	0.85	90	moderate cover, considerable improvement in 1980
Sulphur West			
Tailing Area	1.15	85	good cover on northwest half of area, moderate cover on remainder, some bare spots near banks very toxic, Ky-31 dominant with scattered patches of lespedeza
Tr-1	0.41	85	moderate cover, much improved in 1979, Ky-31 dominant
Boyd Smith	2.03	98	heavy cover except for small areas on southeast end of site, Ky-31 dominant, weeds and trees invading

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[a] To convert hectares to acres multiply by 2.471.

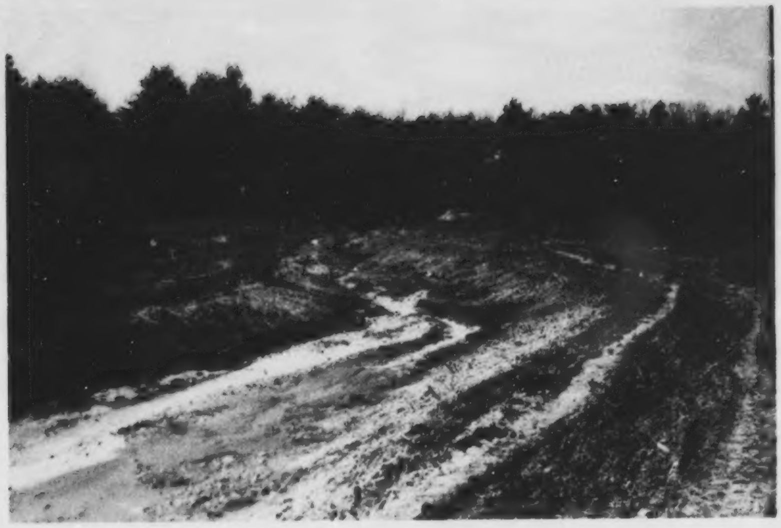

Figure 48. Boyd Smith Site - Spring 1977.

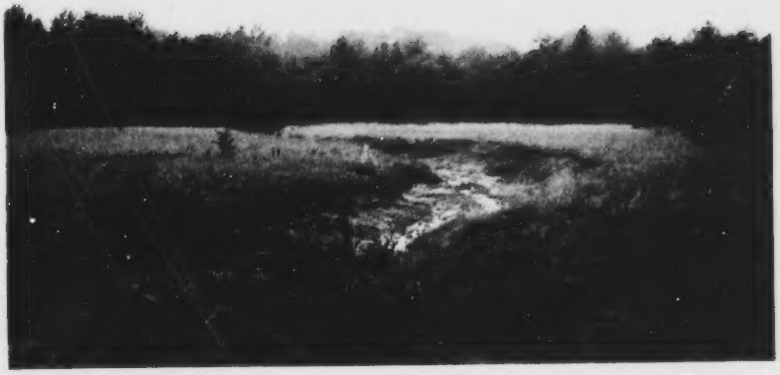

Figure 49. Same view as Figure 48. - Summer 1980.

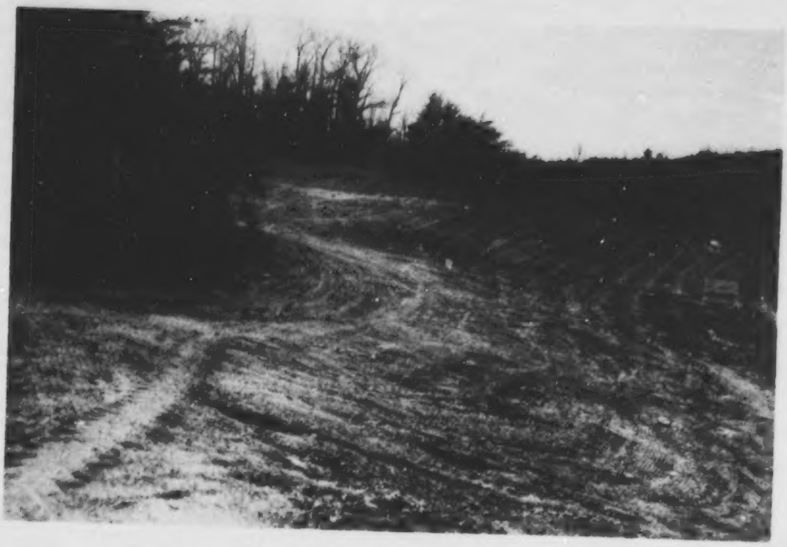

Figure 50. Large Area of Sulphur East - Spring 1977.

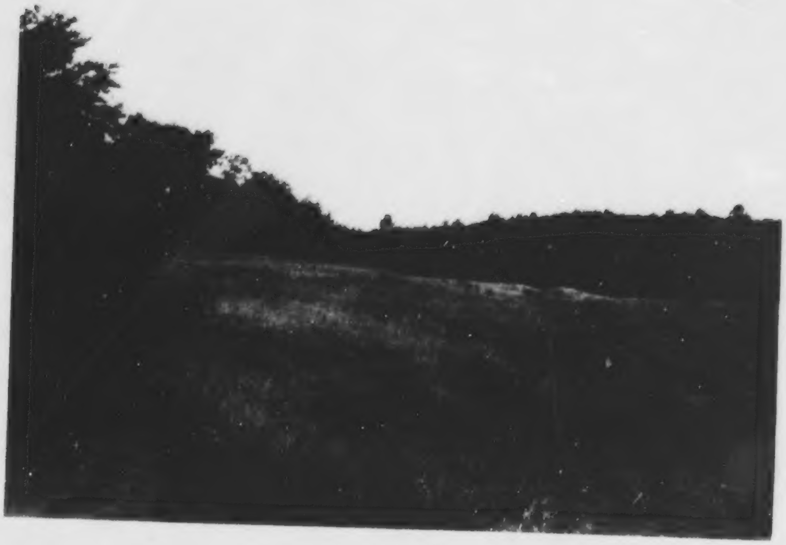

Figure 51. Same view as Figure 50 - Summer 1980.

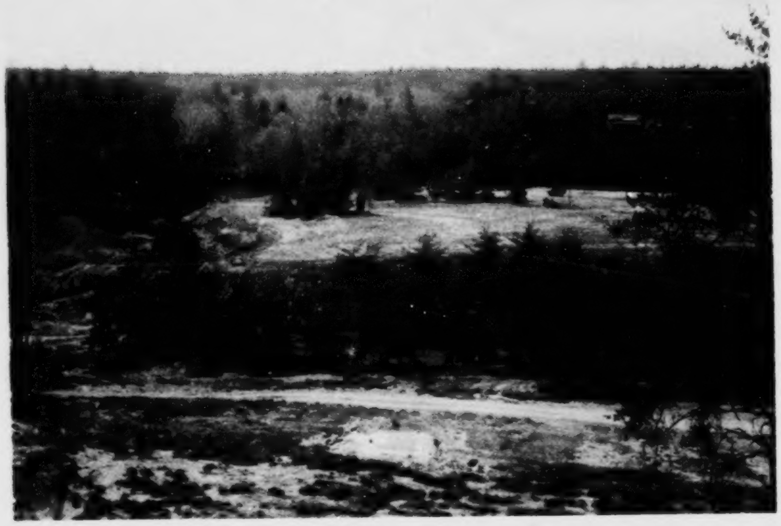

Figure 52. View of Tailing Area of Sulphur West with Tipple Area of Sulphur East in foreground - Spring 1977.

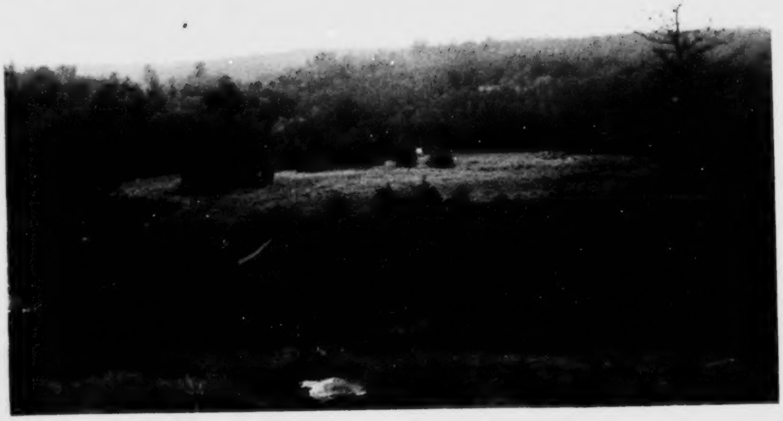

Figure 53. Same view as Figure 52 - Summer 1980. Compare both figures with Figure 6.

it was virtually the only planting that showed any degree of success and it undoubtedly prevented considerable erosion on large portions of Sulphur East until other vegetation could become more established. Even when the lovegrass became dormant in winter, the dry tussocks continued to abate erosion (Figure 55). The lovegrass has been retained in the seed formula since 1977 and the established growth continues to thrive over much of the Large Area and Upstream Flat of Sulphur East.

Both Korean and sericea lespedeza have been used in the seed formula at various times since the reclamation began. These legumes have been moderately successful in a few scattered spots but neither has yet matured enough to reseed itself during a growing season. Red top and ladino clover were tried during the first few years of reclamation, but they were dropped from the seed formula after they failed to show any appreciable degree of success.

Numerous varieties of weeds including foxtail, fall panicum, and smartweed began to invade the Large Area of Sulphur East and the Boyd Smith Site in 1978 and continued to flourish in the summers of 1979 and 1980 and spread to other areas. One of the more encouraging notes was the appearance in the summer of 1979 of at least two species of trees in significant numbers on the Large Area of Sulphur East and the Boyd Smith Site. The most abundant species is a variety of poplar which attained heights of about 0.5 meter the first year.

The general appearance of the stream channel along the upper reach of the Sulphur Site has improved since the reclamation began mainly due to the expanding growth of white grass along the water's edge each summer. This grass grows naturally and is apparently highly acid-tolerant. A few clusters of cattails also began growing in 1978.

The overall assessment of the vegetative cover is that gains continue to be made each year, but it must be realized that there have been only two normal growing seasons since reclamation began. Some of the better areas appear on their way to reverting back to the natural wildlife habitat of the surrounding environs, but other sparsely covered areas with a very thin soil layer supporting vegetation will remain highly vulnerable to drought. Lime and fertilizer should be applied for at least two more years and some of the more toxic areas may need spot seeding. It will probably be several years before a full evaluation of the vegetative cover can be made. It is anticipated that the Glatfelter Pulp Wood Company will again plant pine seedlings on the Sulphur Site once vegetation is more stabilized.

EROSION CONTROL

The Louisa County SCS Field Office used the universal soil loss equation to estimate the degree to which soil loss in tons per acre per year has been reduced on the grassed areas since reclamation began. The soil loss equation was developed by the SCS from rainfall, runoff, and soil loss data collected from 37 research stations over 21 states and has been adapted for use in Virginia as a method for predicting soil loss from sheet erosion. The equation is as follows:

Figure 54. Vigorous growth of Ky-31 fescue on Large Area of Sulphur East - Summer 1979.

Figure 55. Weeping lovegrass on Upstream Flat of Sulphur East - Fall 1979.

$A = KRLSCP$

where

A = average annual predicted soil loss in tons per acre per year
K = soil erodibility factor
R = rainfall factor
L = length of slope factor
S = per cent of slope factor
C = cropping management factor
P = erosion control practice factor

The following are constants for both before and after grass establishment:

$K = .49$
$R = 175$
$P = 1.0$

The following values are used for the cropping management factor (C) according to the cover condition:

No vegetation	- 1.0
Fair	- 0.01
Good	- 0.006
Excellent	- 0.004

L and S values were determined by field measurements. The average annual predicted soil loss (A) computed from the above equation for the various reclamation areas along with the slope factors (L,S) and cropping management factor (C) are shown in Table 28. On the basis of these computations, it appears that soil loss has been reduced in excess of 99 per cent at all of the reclamation areas.

SOIL ANALYSES

As part of the monitoring program various soil analyses have been conducted to determine lime and fertilizer requirements and to compare prereclamation and postreclamation conditions. Initially, composite samples were collected only from Sulphur West, Sulphur East and Boyd Smith, but as specific problem areas became apparent, additional samples were collected to compare covered areas with bare spots and at various depths. Refer to Figure 13 on Page 35 for locations of various collection areas at the Sulphur Site.

The SCS collected composite samples for determiniation of pH and nutrient availability prior to reclamation and have repeated the tests periodically since reclamation. Samples were collected with a soil auger at a depth of around 5 centimeters unless indicated otherwise. All of the SCS samples were analyzed by the Cooperative Extension Service at VPI&SU in Blacksburg, Virginia. Table 29 shows pH and nutrient status of samples collected in 1975 before any reclamation and in 1976 after initial reclamation.

The tests conducted in September 1976 a few months after the first soil additives had been applied indicated dramatic increases in pH and some improvement in nutrient availability, but another test in November 1976 showed a sharp drop in pH. Tables 30-32 give summaries of sludge, lime, and fertilizer applications at the project site since reclamation began. Subsequent tests by the SCS are discussed later in this section.

TABLE 28. SOIL LOSS EQUATION FACTORS FOR BEFORE AND AFTER RECLAMATION

	L S Factor[a]		C Factor[b]		A (tons/ac/yr)	
Area	Before	After	Before	After	Before	After
Sulphur West						
Tailing Area	0.35	0.35	1.0	0.006	30.01	0.18
Tr-1	0.75	0.75	1.0	0.006	64.31	0.39
Sulphur East						
Upstream Flat	0.10	0.10	1.0	0.004	8.58	0.05
Large Area	2.2	1.55	1.0	0.006	188.65	0.53
Tipple Area	3.80	3.80	1.0	0.006	325.85	1.96
North End	0.30	0.30	1.0	0.006	25.73	0.15
Boyd Smith	0.65	0.65	1.0	0.004	55.74	0.22

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[a] Determined by multiplying length of slope by per cent of slope. It is assumed that these factors were the same before and after reclamation except in the Large Area of Sulphur East where a diversion was constructed.

[b] 1.0 = no vegetation, 0.006 = good cover, 0.004 = excellent cover.

TABLE 29. SOIL DATA - SCS
pH - NUTRIENT AVAILABILITY[a] - 1975-76

Area - Date	pH	CaO	MgO	P_2O_5	K_2O
Sulphur West					
11-75	2.4	L-	H	L-	L-
9-76	6.0	VH	VH	VH	H-
11-76	3.8	VH	VH	VH	M
Sulphur East					
11-75	2.2	VH	VH	L-	L-
9-76	5.6	VH	H	VH	H
11-76	3.1	VH	H	VH	M-
Boyd Smith					
11-75	3.1	L-	H+	L-	L-
9-76	6.1	VH	VH	VH	L
11-76	5.4	VH	VH	VH	L-

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[a] VH - very high H - high M- medium L-low

TABLE 30. SUMMARY OF SLUDGE APPLICATION

Year	Total tonnes[a] (wet)	Avg.% Solids	Total tonnes (dry)	Total ha Sludged	Tonnes/ha[b] (dry)
1976					
Sulphur	5443	22	1197	4.6	260
Boyd Smith	1814	22	399	2.0	200
1977	1769	19.9	352	1.6	220
1978	544	20.3	110	0.8	138
1979[c]	308	19.5	60	0.7	82
TOTAL	9878		2118		

---

[a] To convert tonnes to tons multiply by 1.1023.

[b] To convert tonnes/ha to tons/ac multiply by 0.449.

[c] Includes a very small portion of Boyd Smith Site, but no breakdown is made.

TABLE 31. SUMMARY OF LIME APPLICATION RATES - 1976 - 80 (tonnes/ha)[a]

Area	Size (ha)[b]	Summer 1976	Spring 1977	Fall 1977	Spring 1978	Fall 1978	Spring 1979	Fall 1979	Spring & Fall 1980	Total
Sulphur East										
Upstream Flat	0.41	8.9	31.2			11.1	8.9[d]	17.8	8.9	95.7
Large Area	2.23	8.9	13.4		22.3[c]	33.4[c]	4.5	8.9	8.9	109.2
Tipple Area	0.57	8.9	13.4		22.3	22.3	17.8	17.8	8.9	120.3
North End	0.72	8.9	13.4		22.3	22.3	8.9[d]	17.8	8.9	111.4
Sulphur West										
Tailing Area	1.17	8.9	22.3	22.3	22.3	11.1	8.9[d]	22.3	8.9	135.9
Tr-1	0.32	8.9	31.2			33.4	17.8	8.9	8.9	118.0
Boyd Smith	2.03	8.9	13.4				4.5	22.3[e]	8.9[f]	56.9

[a] To convert tonnes/ha to tons/ac multiply by 0.449.
[b] To convert hectares to acres multiply by 2.471.
[c] Stream banks only.
[d] Bare spots only, remainder of each area received 4.5 tonnes/ha.
[e] Seeded areas only.
[f] North side only.

TABLE 32. SUMMARY OF FERTILIZER TYPES AND APPLICATION RATES - 1976 - 80 (Kg/ha)[a]

		Summer 1976		Spring 1977				Spring 1979	Fall 1979	Spring 1980	Fall 1980
Area	Size (ha)[b]	10-10-10	38-0-0	10-10-10	38-0-0	16-7-12	18-18-6	6-6-12	6-0-12	6-0-12	6-6-12
Sulphur East											
Upstream Flat	0.41	1121	448				897	1121	1121	1121	1121
Large Area	2.23	1121	448[c]	561	448[c]	336[d]	336[d]	1121	1121	1121	1121
Tipple Area	0.57	1121		561				1121	1121	1121	1121
North End	0.72	1121	448[c]	561				1121	1121	1121	1121
Sulphur West											
Tailing Area	1.17	1121	448[c]	561	448[c]	336[d]	336[d]	1121	1121	1121	1121
Tr-1	0.32	1121	448			897		1121	1121	1121	1121
Boyd Smith	2.03	1121		561		336[d]	336[d]	1121	1121	1121	1121

[a] To convert Kg/ha to lbs/ac multiply by 0.892.

[b] To convert hectares to acres multiply by 2.471.

[c] Stream banks only.

[d] 0.405 hectare (1 ac) of each area was treated with 16-7-12 and 18-18-6, respectively.

Composite soil samples were also collected in the same manner by the SWCB and analyzed by the DCLS to determine lime requirements by titration and metals content using special tests prescribed by the EPA Project Officer. Procedures are described in Appendix B. Table 33 shows initial pH and lime requirements for the various work areas from 1976 to 1979 as determined by titration.

The results of the soil analyses were used as guidelines for developing the specifications for lime application rates during each period of maintenance. Where repetitive samples were collected from the same area, it can be seen that lime requirements varied considerably. Note that the sample collected from the Tailing Area of Sulphur West in March 1979 was from the barren or most severe area and did not necessarily represent conditions over the entire area. From the pH and lime requirement data, it appears that soil conditions improved appreciably at Tr-1 on Sulphur West during 1978. This has been one of the most severe areas to work with since the project began. In general, the pH of the soils has been raised and lime needs appear to have declined, but some areas, particularly the Tailing Area and the North End of the Sulphur Site, will probably require heavy liming for sometime to maintain vegetation.

Table 34 shows metal analyses of composite soil samples collected over the entire project area. It can be seen that there is a wide range in metals content over the various areas, but a very pronounced decrease in metal concentrations occurred in some of the worst areas in 1978 and 1979. This undoubtedly resulted from the continued heavy application of soil additives and indicates less toxic soil at the surface over much of the reclaimed areas, but it is likely that the underlying material is still heavily laden with metals.

At the request of the EPA Project Officer a special set of samples was collected in March 1978 and sent to the soil testing laboratory at West Virginia University to determine total potential acidity, lime requirements, and nutrient availability. The results are shown in Table 35. See Table 33 for a comparison of lime requirements. Note the extremely low availability of potassium in some areas of the Sulphur Site.

During 1979 the SCS collected three sets of composite soil samples for continued study of nutrient availability. The first collection made in March (Table 36) was concurrent with a collection made by the SWCB for titration tests and metal analyses (Tables 33-34), and samples were split from the same borings. Numerical values of nutrient availability in pounds per acre are included in Table 36. Note the extremely low availability of potash (K_2O) in all areas except the Large Area of Sulphur East and the Boyd Smith Site. The lowest potash availability was on the Tailing Area of Sulphur West and on the stream bank opposite Tr-1 and the North End of Sulphur East, all of which have been difficult to vegetate.

Another set of samples collected by the SCS in July 1979 (Table 37) showed the same general trend in potash deficiency, and comparisons between grassy and barren spots of the Tailing Area and the Tipple Area revealed slightly higher potash where grass was growing. This was after the applica-

TABLE 33. SOIL DATA - DCLS
pH, LIME REQUIREMENT BY TITRATION CURVE

Area - Date	Initial pH	Lime Required to attain pH of 6.5 (tonnes/ha)	Accumulative total of lime applied prior to each test (tonnes/ha)
SULPHUR WEST			
Tailing Area			
11-76	4.1	21.6	8.9
6-77	3.1	40.1	31.2
3-78	5.1	24.0	53.5
6-78	5.9	4.6	75.8
3-79[a]	4.5	40.1	84.7
Tr-1			
11-76	3.7	30.5	8.9
11-76[b]	3.9	50.1	8.9
3-78	3.6	34.3	40.1
3-79	6.5	11.1	40.1
SULPHUR EAST			
Opposite Tr-1			
6-78	2.7	42.7	44.6
Stream Bank of Large Area			
3-79	4.5	31.2	66.9
Upstream Flat			
11-76	7.3	0	8.9
3-78	6.7	0	40.1
7-78	5.7	5.3	40.1
3-79	5.4	18.5	51.2
Large Area			
11-76	5.5	13.4	8.9
3-78	7.3	0	22.3
Tipple Area			
3-78	3.2	36.6	22.3
6-78	3.0	40.7	44.6
3-79	5.9	22.3	66.9
North End			
3-79	5.7	28.9	66.9
BOYD SMITH			
11-76	5.4	7.8	8.9

[a] Bare spots only.

[b] Dark material only.

TABLE 34. SOIL DATA - DCLS, pH AND METALS ON DRY WEIGHT BASIS (mg/kg)

Area-Date	pH	Cu	Fe	Pb	Mn	Zn	Al
SULPHUR WEST							
Tailing Area							
11-76	4.1	50	30	ND[a]	74	262	
6-77	3.1	62	34	--	17	82	132
3-78	5.1	0.1	7.8	0.2[b]	6.8	6.6	1.0
6-78	5.9	1.0	24	0.2-	3.6	1.5	2.4
3-79[c]	4.5	3.2	7.6	0.01	6.4	28.0	1.0
2-80	4.9	0.2	0.4	0.2-	2.6	3.4	1.0-
Tr-1							
11-76	3.7	288	220	4.6	152	3940	
11-76[d]	3.9	820	160	5.4	236	5200	
3-78	3.6	226	340	2.4	7.4	366	32
3-79	6.5	0.9	0.2-	0.002	2.9	1.6	1.0-
2-80	5.3	0.6	0.6	0.2-	4.8	17.8	2.0-
SULPHUR EAST							
Opposite Tr-1							
6-78	2.7	66	1600	2.4	7.2	252	324
3-79	5.9	0.9	0.2	0.011	3.8	11.0	1.0-
2-80	4.7	1.1	1.2	0.2-	6.0	18.6	2.0-
Stream Bank of Large Area							
3-79		1.2	3.6	0.011	0.6	21.6	1.0
2-80	3.8	4.6	10.4	0.2-	3.8	15.4	4.0
Large Area							
11-76	5.5	8.6	4.2	ND	31.4	18.8	
3-78	7.3	0.3	6.2	0.2	0.5	0.1	2.0
3-79	5.9	0.3	3.6	0.005	1.9	1.2	1.0-
2-80	5.2	0.2	0.8	0.2	1.7	3.4	2.0-
Upstream Flat							
11-76	7.3	2	ND	ND	31.6	54	
3-78	6.7	0.1	5.0	0.2	6.6	4.0	1.0-
7-78	5.7	1.0	5.0	0.2-	14.4	3.2	3.2
3-79	5.4	1.9	0.6	0.014	25.9	150	1.0-
2-80	5.5	0.6	0.8	0.2-	12.2	12.8	

(continued)

TABLE 34. (continued)

Area-Date	pH	Cu	Fe	Pb	Mn	Zn	Al
Tipple Area							
3-78	3.2	5.0	80	0.2	0.8	6.2	6.6
6-78	3.0	28	620	0.2-	3.0	24	100
3-79	5.9	0.1	0.6	0.001	3.9	2.0	1-
2-80	4.7	1.1	4.8	0.2-	4.6	10.2	2-
North End							
3-79		0.2	0.8	0.008	2.2	3.8	1.0
2-80	4.9	0.1	0.4	0.2-	7.2	0.7	2-
BOYD SMITH							
11-76	5.4	0.7	0.6	ND	30.6	19.6	
6-78	7.1	0.3	1.0	0.2-	1.6	0.8	1.2
3-79	5.7	1.1	0.2	0.011	7.0	19.6	1-
2-80	5.0	1.0	0.4	0.2-	6.0	12.6	2-

---

[a] ND-None detected. Detection Limit is 0.2 mg/kg.

[b] A (-) sign indicates that the concentration was below the indicated level of detection.

[c] Bare spots only.

[d] This sample consisted primarily of dark material only.

TABLE 35. SOIL DATA - WVU,
pH, LIME REQUIREMENT, NUTRIENT AVAILABILITY, TOTAL POTENTIAL ACIDITY - MARCH 1978

Sample Area	pH	L.R.[a]	K[b]	Ca[c]	Mg[d]	% S[e]	Maximum from % S[f]	Amount Present[g]	Maximum Needed (pH 7)[h]
Sulphur West									
Tailing Area	5.3	2.0	75	11,200	405	5.225	163.28	7.85	155.43
Sandwich Area	6.8	0	178	12,200	435	3.150	98.44	26.48	71.96
Tr-1	4.4	6.0	184	4,800	165	2.600	81.25	-9.55	90.80
Sulphur East									
Upstream Flat	6.8	0	75	10,400	375	0.850	26.56	14.23	12.33
Large Area	6.7	0	164	13,600	450	2.450	76.56	29.90	46.66
Tipple Area	3.9	6.4	16	6,500	90	2.675	83.59	-6.61	90.20

[a] Lime requirement in tons/ac to acquire a pH of 6.5.

[b] Amount of acid extractable K in sample in lbs/1000 tons of material. Multiply K by 1.2 to obtain K_2O.

[c] Amount of acid extractable Ca in sample in lbs/1000 tons of material.

[d] Amount of acid extractable Mg in sample in lbs/1000 tons of material.

[e] Per cent sulfur in sample as detected by LECO induction furnace.

[f] Maximum amount of acid that can be produced from % sulfur present in sample expressed in terms of $CaCO_3$ equivalents in tons/1000 tons of material. Derived by multiplying % S by 31.25.

[g] Amount of neutralizers present in sample expressed in $CaCO_3$ equivalents in tons/1000 tons of material as determined by the neutralization potential. Negative numbers indicate the presence of free acid.

[h] Amount of neutralizers required to neutralize the maximum acidity possible from % S in tons/1000 tons of material.

TABLE 36. SOIL DATA - SCS, pH AND NUTRIENT AVAILABILITY IN LBS/AC - MARCH 1979[a]

Area	pH	CaO	Mgo	P_2O_5	K_2O
Sulphur West					
Tailing Area[b]	3.7	3358 (VH)	207 (M+)	250+(VH)	12 (L-)
Tr-1	5.5	3358 (VH)	398 (VH)	247 (H+)	41 (L)
Sulphur East					
Opposite Tr-1	4.9	3358 (VH)	398 (VH)	250+(VH)	26 (L)
Stream Bank of Large Area	4.6	3358 (VH)	398 (VH)	224 (H+)	8 (L-)
Large Area	5.3	3358 (VH)	398 (VH)	137 (H)	154 (M)
Upstream Flat	4.8	3358 (VH)	255 (H-)	250+(VH)	60 (L)
Tipple Area	5.1	3358 (VH)	398 (VH)	250+(VH)	26 (L)
North End	4.6	3358 (VH)	398 (VH)	250+(VH)	1 (L-)
Boyd Smith	6.0	3358 (VH)	398 (VH)	231 (H+)	298 (H)

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[a] VH-very high, H-high, M-medium, L-low.
[b] Bare spots only.

tion of 6-6-12 fertilizer in the spring of 1979 (Table 32) which was the first fertilizer that had been applied since the spring of 1977. Note that pH was around two units higher in the grassed areas than in the bare spots.

TABLE 37. SOIL DATA - SCS
pH, NUTRIENT AVAILABILITY - JULY 1979

Area	pH	CaO	MgO	P_2O_5	K_2O
Sulphur West					
Tailing Area					
Grass	4.4	VH	VH	H	L
Barren	2.2	VH	VH	VH	L-
Sulphur East					
Large Area	5.9	VH	VH	M-	H+
Upstream Flat	3.7	VH	VH	VH	L+
Tipple Area					
Grass	4.6	VH	VH	VH	M-
Barren	2.8	VH	VH	VH	L-
North End	3.8	VH	VH	VH	L
Boyd Smith	5.9	VH	VH	H	H

[a] VH - very high, H - high, M - medium, L - low.

In October 1979 after application of more lime and 6-0-12 fertilizer (Tables 31-32) samples were collected on the Tailing Area of Sulphur West and the Large Area of Sulphur East to compare soil conditions near the surface and at depth in grassed and barren areas (Table 38). In the Tailing Area it can be seen that pH was somewhat higher in the topsoil where there was ground cover, but at depth the pH was identical in grassed and barren spots. Most of the nutrients tended to be lower at depth, but potash was very low regardless of cover or depth. The Large Area of Sulphur East showed the same general pattern of pH, but nutrient availability was generally higher near the surface. The sample collected along the stream bank opposite Tr-1 with the extremely low pH of 1.1 consisted primarily of pyritic material, but interestingly it was not the most nutrient deficient.

Continued soil analyses conducted in 1980 showed a marked improvement between March and August (Table 39) in pH and potash availability over all areas, but there was a decrease in phosphate (P_2O_5) availability. Fertilizer

TABLE 38. SOIL DATA - SCS, pH NUTRIENT AVAILABILITY - OCTOBER 1979[a]

Area	Depth (cm)	pH	CaO	MgO	P_2O_5	K_2O
Sulphur West						
Tailing Area						
Grass	5	3.6	VH	M+	VH	L-
	61	2.5	VH	M-	M-	L-
Barren	5	2.9	VH	L	VH	L-
	46	2.5	VH	H-	L+	L-
Sulphur East						
Large Area						
Grass	5	5.0	VH	M+	M	H-
	30	3.2	L+	L-	L	L+
Barren	46	2.9	L+	VH	L	L
Opposite Tr-1						
Barren[b]	0	1.1	M-	VH	L	M

[a] VH-very high, H-high, M-medium, L-low.
[b] Consisted primarily of pyritic material.

of the type 6-6-12 was again used in the fall of 1980.

In summary, it appears that a viable soil cover is gradually being established over most of the reclaimed areas, but there are still some very toxic spots supporting no vegetation and in other areas the soil horizon that does support vegetation is indeed very thin. A major unvegetated area is the steep banks along the creek. Not only are they toxic, but lime, fertilizer, sludge, and seed are difficult to apply and they erode easily. Without the heavy application of lime, fertilizer and especially the sludge, there would unquestionably be little if any vegetation growing on the reclaimed sites. It appears that potash availability is a key limiting factor in the establishment of vegetation in areas with adequate lime and sludge. A high potash fertilizer should be used for any future maintenance. The thin mantle of growth supporting media overlying the toxic mine wastes

TABLE 39. SOIL DATA - SCS, pH AND NUTRIENT AVAILABILITY IN LBS/AC - 1980[a]

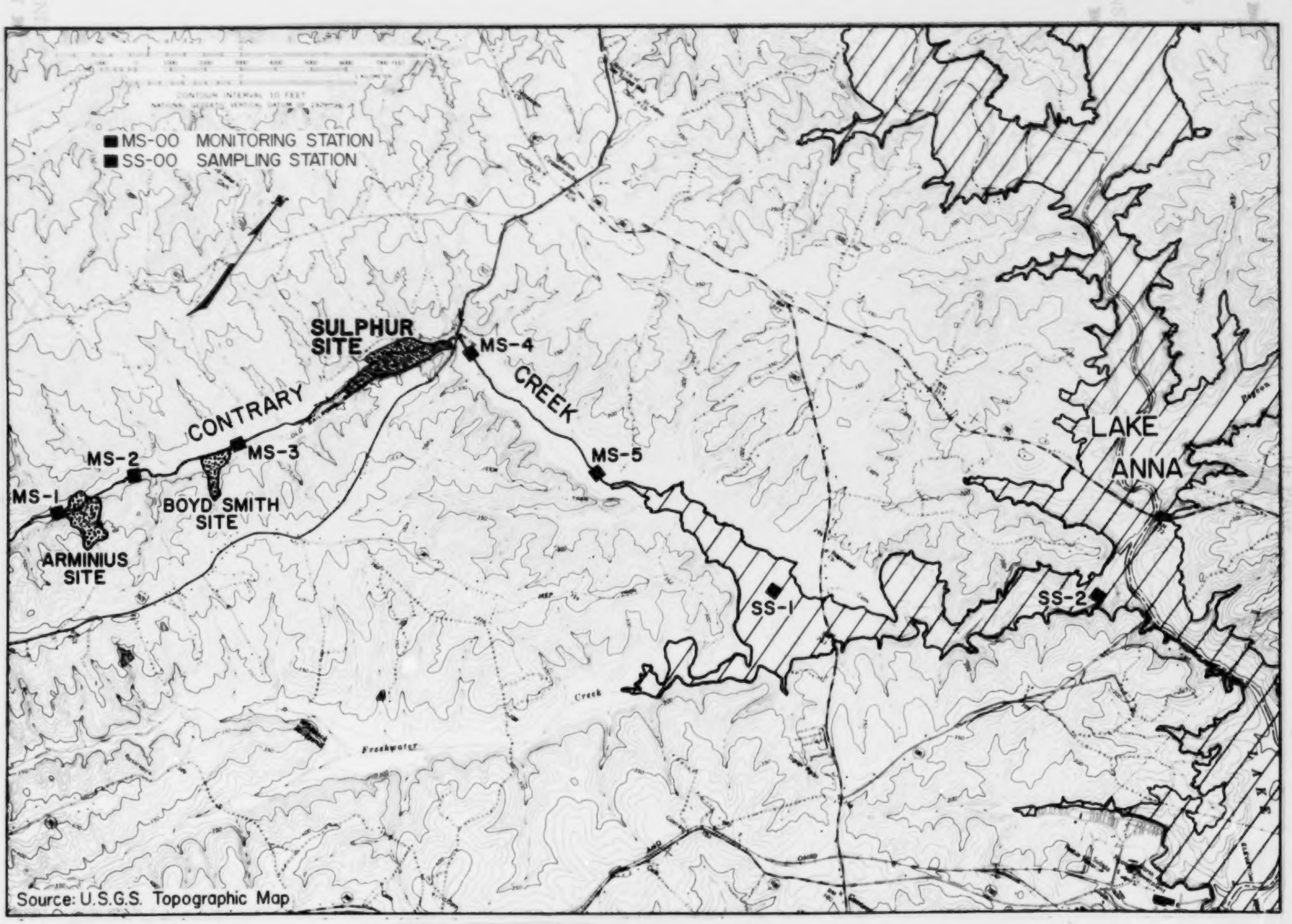
Area	pH		P_2O_5		K_2O	
	Mar	Aug	Mar	Aug	Mar	Aug
Sulphur West						
Tailing Area	3.0	6.1	275(VH)	32(M-)	7(L-)	124(M)
Barren Spots		3.1		275(VH)		38(L)
Tr-1	4.4	6.3	275(VH)	32(M-)	75(L+)	155(M)
Sulphur East						
Large Area	4.1	6.6	275(VH)	32(M-)	117(M-)	124(M)
Upstream Flat	4.9	6.3	275(VH)	60(M)	147(M)	186(M+)
Tipple Area	5.5	5.7	160(VH)	209(M)	80(L+)	110(M-)
North End	3.9	6.0	275(VH)	32(M)	34(L)	41(L)
Boyd Smith	4.1	6.2	275(VH)	128(H)	94(M-)	275(H)

[a] VH-very high, H-high, M-medium, L-low

presents a condition that is very drought sensitive. Since the plant root system is very shallow, short periods without precipitation result in plant damage. Soil tests will continue to be conducted periodically to evaluate progress toward a soil profile that will support permanent vegetation.

WATER QUALITY

A detailed water quality monitoring program began in October 1975 six months prior to start of reclamation work and is still in progress. Until early 1980 water samples were collected semi-monthly from five stream stations and two lake stations except when inclement weather or manpower constraints curtailed operations. In April 1980 the stream sampling was reduced to once monthly and all lake sampling was discontinued. A brief description of each monitoring station is given below, and Figure 56 shows locations of the stations.



Source: U.S.G.S. Topographic Map

FIGURE 56. CONTRARY CREEK MONITORING STATIONS

Stations Located on Contrary Creek -

MS-1	Control station above all mine sites
MS-2	Below Arminius Site
MS-3	Below Boyd Smith Site
MS-4	Below Sulphur Site
MS-5	Mouth of Contrary Creek just above Lake Anna

Lake Stations -

SS-1	Contrary Creek arm of Lake Anna
SS-2	Juncture of Contrary Creek arm with main body of Lake Anna

Surface, middle, and bottom samples were collected from each lake station making a total of 11 samples for each collection. A list of the parameters analyzed from the regular sampling follows.

pH
Acidity
Sulfate
Copper
Iron
Lead
Manganese
Zinc
Suspended Solids
Turbidity
BOD (5-day)
Fecal Coliform

BOD and fecal coliform analyses were included in the regular analyses to ascertain if the use of wastewater sludge had any effects upon the water of the stream. Analyses were conducted on the sludge itself during the main phase of construction. For results see Table 9 on Page 46. Additional parameters including some less common metals and some nutrients were analyzed at all stations at least once annually, and grab samples were collected periodically from various tributaries at each mine site. A special study funded from the EPA grant was conducted by the University of Virginia in 1978 to identify specific sources and magnitude of AMD along the stream and to determine the effects of heavy rainstorms on stream chemistry. The SWCB followed this study up with pH and specific conductivity transects during the summer of 1979. Results of the water quality monitoring will now be presented.

Stream Stations - Concentration and Load Data

All stream stations were equipped with automatic flow recorders except MS-5 where flows were measured with a current meter. Mean annual flows for the stations with continuous records covering five water years from 1976 to 1980 are shown in Table 40.

TABLE 40. MEAN ANNUAL FLOWS (l/s)[a]

Water Year	MS-1	MS-2	MS-3	MS-4
1976	48.7	54.9	94.3	147.8
1977	32.6	36.3	62.6	94.6
1978	73.9	87.2	140.2	206.5
1979	66.6	82.4	140.5	198.8
1980	50.8	68.2	115.5	153.1

[a] To convert l/s to cfs multiply by 0.0353.

Tables 41 - 44 show average values of flows, concentrations, and loads for key parameters at stream stations MS-1 thru MS-4 by quarter for water years 1976 thru 1980. Table 45 gives average concentrations only for MS-5 where no continuous flow data are available. Concentration values from the semi-monthly samplings were averaged, and loads were computed by multiplying average concentrations by the quarterly average daily flows. While this method of averaging loads does not fully reflect the effects of sudden flushings of AMD loads from the mine sites, it gives a general picture of seasonal trends. It can be seen from the concentration and load averages that there has been little overall change in water quality during the five-year period. Concentrations and loads for some pollutants tended to be somewhat lower in water years 1979 and 1980, but it is too early to discern if an improved trend is beginning to emerge. Some of the apparent decreases in loads may be more attributable to lower flows during the dry summer months. The sharp increases in concentrations during the last quarter of water year 1980 were primarily due to the very low flows during the summer drought.

Comparing the quarterly concentration averages with the water quality standards presented in Section 4, it is apparent that acid and heavy metals have consistently exceeded SWCB limits at most stream stations. For any given quarter, pH usually averaged below the standard of 6.0 at MS-2, only exceeded 6.0 once at MS-3, never exceeded 4.4 at MS-4, and only once averaged as high as 4.0 at MS-5. Sulfate concentrations usually averaged above the limit (250 mg/l) at all affected stations during low flow, and copper usually exceeded the 1.0 mg/l limit at MS-4 and MS-5 during the last quarter of each water year. Lead often exceeded the limit of 0.05 mg/l at MS-4 and sometimes was above the standard at the other affected stations during low flows. Zinc regularly exceeded the limit of 5.0 mg/l at MS-2 and MS-4 during low flow periods and occasionally did so at MS-3 and MS-5. Iron and manganese concentrations almost always exceeded standards, 0.3 mg/l and 0.05 mg/l, respectively, at all stations including the control MS-1 indicating the ubiquity of these metals, but obviously the Sulphur Site is the major contributor of iron. Manganese appears to increase most abruptly at the Boyd Smith Site.

For a more detailed picture of pH and concentrations, a series of graphs were constructed from the data in STORET to show individual pH values and concentrations determined from the semi-monthly sampling at each station.

TABLE 41. SUMMARY OF WATER QUALITY DATA BY QUARTER AT MS-1

Quarter	1	2	3	4	1	2	3	4
	Flow (l/s)				pH			
Water Year[a]								
1976	51.8	91.8	42.8	8.8	6.5	6.1	6.0	7.6
1977	72.8	37.4	20.1	0.6	6.7	6.9	7.2	7.9
1978	62.6	129.4	84.4	20.7	7.5	6.1	7.1	6.8
1979	21.8	161.4	68.3	17.3	6.4	5.6	6.6	6.9
1980	62.4	95.3	37.9	6.5	6.6	6.1	6.7	6.9
	Concentration (mg/l)				Load (kg/d)			
				Acidity				
1976	6	15	6	4	27	119	22	3
1977	6	9	5	10	38	291	9	1
1978	12	10	9	5	65	112	66	9
1979	8	26	59	7	15	363	348	10
1980	7	10	12	11	38	82	39	6
				Sulfate				
1976	8	9	7	4	36	71	26	3
1977	8	7	6	18	50	23	10	1
1978	19	17	11	15	103	55	80	27
1979	11	20	8	14	21	279	47	21
1980	11	15	9	10	59	124	29	6
				Copper				
1976	0.02	0.02	0.03	0.01	0.09	0.16	0.11	0.01
1977	0.01	0.01	0.03	0.01	0.06	0.03	0.05	0.00
1978	0.04	0.04	0.06	0.04	0.22	0.45	0.44	0.07
1979	0.02	0.10	0.03	0.03	0.04	1.39	0.18	0.04
1980	0.05	0.05	0.03	0.03	0.27	0.41	0.10	0.02
				Iron				
1976	0.9	0.5	1.5	1.6	4.0	4.0	5.5	1.2
1977	0.8	0.7	1.6	0.5	5.0	2.3	2.8	0.0
1978	0.6	0.5	1.5	2.5	3.2	5.6	10.9	4.5
1979	1.5	0.6	2.2	2.2	2.8	8.4	13.0	3.3
1980	1.7	0.6	1.6	1.4	9.2	4.9	5.2	0.8

(continued)

TABLE 41. (continued)

Quarter	1	2	3	4	1	2	3	4
Water Year [a]	Concentration (mg/l)				Load (kg/d)			
				Lead				
1976	0.009	0.004	0.007	0.039	0.04	0.03	0.03	0.03
1977	0.016	0.010	0.012	0.003	0.10	0.03	0.02	0.00
1978	0.003	0.007	0.007	0.013	0.02	0.08	0.05	0.02
1979	0.008	0.018	0.006	0.005	0.02	0.25	0.04	0.01
1980	0.007	0.006	0.005	0.011	0.04	0.05	0.02	0.01
				Manganese				
1976	0.04	0.08	0.16	0.04	0.2	0.6	0.6	0.0
1977	0.14	0.10	0.12	0.24	0.9	0.3	0.2	0.0
1978	0.20	0.11	0.11	0.17	1.1	1.2	0.8	0.3
1979	0.04	0.17	0.12	0.07	0.1	2.4	0.7	0.1
1980	0.16	0.12	0.08	0.07	0.9	1.0	0.3	0.0
				Zinc				
1976	0.1	0.1	0.1	0.0	0.2	0.6	0.3	0.0
1977	0.1	0.1	0.1	0.2	0.4	0.2	0.2	0.0
1978	0.2	0.2	0.2	0.2	1.1	1.9	1.2	0.3
1979	0.1	0.4	0.3	0.1	0.2	5.6	1.8	0.2
1980	0.3	0.2	0.1	0.2	1.6	1.6	0.3	0.1

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[a] A water year begins October 1 and ends September 30. 1st quarter, Oct. - Dec; 2nd quarter, Jan - March; 3rd quarter, April - June; 4th quarter, July - Sept.

TABLE 42. SUMMARY OF WATER QUALITY DATA BY QUARTER AT MS-2

Quarter	1	2	3	4	1	2	3	4
	Flow (l/s)				pH			
Water Year								
1976	64.3	95.4	47.9	12.2	5.9	5.4	5.8	4.8
1977	78.5	41.1	24.1	1.1	5.7	6.2	5.8	3.3
1978	64.9	156.6	102.5	26.3	4.9	5.6	6.6	5.8
1979	28.9	204.8	78.2	20.1	6.0	5.5	6.2	5.8
1980	71.1	135.9	56.9	8.5	6.3	6.0	6.2	4.7
	Concentration (mg/l)				Load (kg/d)			
	Acidity							
1976	16	20	8	44	89	165	33	46
1977	12	14	32	309	81	50	167	30
1978	60	18	18	14	336	244	159	32
1979	19	41	71	18	47	725	480	32
1980	18	13	13	70	111	152	64	51
	Sulfate							
1976	72	50	48	200	400	412	199	211
1977	85	65	161	1052	577	231	335	100
1978	93	42	64	115	521	568	567	261
1979	114	49	57	109	285	867	385	189
1980	61	45	68	491	375	529	334	361
	Copper							
1976	0.10	0.11	0.09	0.30	0.56	0.91	0.37	0.32
1977	0.17	0.10	0.25	3.02	1.15	0.36	0.52	0.29
1978	0.20	0.11	0.11	0.13	1.12	1.49	0.97	0.30
1979	0.11	0.11	0.08	0.09	0.27	1.95	0.54	0.16
1980	0.09	0.08	0.06	0.36	0.55	0.94	0.29	0.26
	Iron							
1976	2.0	1.3	2.3	3.7	11.1	10.7	9.5	3.9
1977	3.0	1.9	2.4	7.1	20.3	6.7	5.0	0.7
1978	1.9	1.3	1.4	1.7	10.7	17.6	12.4	3.9
1979	1.7	1.0	1.9	1.3	4.2	17.7	12.8	2.3
1980	1.8	1.8	1.0	1.7	11.1	21.1	4.9	1.2

(continued)

TABLE 42. (continued)

Quarter	1	2	3	4	1	2	3	4
Water Year	Concentration (mg/l)				Load (kg/d)			
				Lead				
1976	0.013	0.018	0.019	0.075	0.07	0.15	0.08	0.08
1977	0.102	0.057	0.048	0.625	0.69	0.20	0.10	0.06
1978	0.030	0.015	0.020	0.029	0.17	0.20	0.18	0.06
1979	0.022	0.028	0.012	0.016	0.06	0.50	0.20	0.03
1980	0.019	0.006	0.014	0.096	0.12	0.07	0.07	0.07
				Manganese				
1976	0.52	0.39	0.43	1.57	2.9	3.2	1.8	1.7
1977	1.04	0.59	1.38	7.68	7.1	2.1	2.9	0.7
1978	0.47	0.36	0.59	0.86	2.6	4.9	5.2	2.0
1979	0.61	0.40	0.63	0.92	1.5	7.1	4.3	1.6
1980	0.51	0.41	0.59	1.49	3.1	4.8	2.9	1.1
				Zinc				
1976	4.4	2.8	3.1	12.9	24.4	23.1	12.8	13.6
1977	8.8	4.3	8.9	54.7	59.7	15.3	18.5	5.2
1978	3.5	2.7	3.5	8.6	19.6	36.5	31.0	19.5
1979	7.3	2.7	4.4	5.7	18.2	47.8	29.7	9.9
1980	5.1	2.7	3.4	21.0	31.3	31.7	16.7	15.4

TABLE 43. SUMMARY OF WATER QUALITY DATA BY QUARTER AT MS-3

Quarter	1	2	3	4	1	2	3	4
	Flow (l/s)				pH			
Water Year								
1976	103.9	158.3	89.2	27.2	5.0	4.9	5.3	4.3
1977	132.8	76.5	36.8	4.5	5.3	6.3	5.8	3.7
1978	113.8	233.6	167.7	47.6	4.7	4.9	5.1	4.8
1979	42.8	342.4	137.6	43.0	5.4	4.8	5.1	4.6
1980	126.0	226.8	86.4	21.0	5.8	5.6	5.3	4.5
	Concentration (mg/l)				Load (kg/d)			
	Acidity							
1976	16	17	10	40	144	233	77	94
1977	23	20	31	81	264	132	99	31
1978	41	20	27	20	403	404	391	82
1979	20	48	75	23	74	1420	892	85
1980	14	16	17	27	152	314	127	49
	Sulfate							
1976	127	74	76	248	1140	1012	586	583
1977	78	90	153	476	895	595	486	185
1978	136	62	92	192	1337	1251	1333	790
1979	173	62	98	125	640	1834	1165	464
1980	88	27	110	269	958	529	821	488
	Copper							
1976	0.15	0.15	0.39	0.32	1.4	2.1	3.0	0.8
1977	0.20	0.16	0.15	0.74	2.3	1.1	0.5	0.3
1978	0.18	0.16	0.12	0.13	1.8	3.2	2.4	0.5
1979	0.36	0.15	0.14	0.14	1.3	4.4	1.7	0.5
1980	0.13	0.12	0.10	0.58	1.4	2.4	0.7	1.1
	Iron							
1976	2.2	1.7	7.5	1.4	19.7	23.3	57.8	3.3
1977	2.4	1.9	1.4	1.2	27.5	12.6	4.5	0.5
1978	2.2	1.8	1.5	1.3	21.6	36.3	21.7	5.3
1979	1.3	1.5	2.0	1.0	4.8	44.4	23.8	4.1
1980	1.7	1.8	1.6	1.0	18.5	35.3	11.9	1.8

(continued)

TABLE 43. (continued)

Quarter	1	2	3	4	1	2	3	4
Water Year	Concentration (mg/l)				Load (kg/d)			
				Lead				
1976	0.026	0.015	0.200	0.105	0.23	0.21	1.50	0.25
1977	0.037	0.018	0.032	0.124	0.43	0.12	0.10	0.05
1978	0.033	0.023	0.036	0.029	0.32	0.46	0.52	0.12
1979	0.019	0.028	0.023	0.027	0.07	0.83	0.27	0.10
1980	0.021	0.015	0.014	0.019	0.23	0.29	0.10	0.03
				Manganese				
1976	1.50	0.94	2.20	4.32	13.5	12.9	17.0	10.2
1977	1.33	1.40	1.97	8.16	15.3	9.3	6.3	3.2
1978	2.00	0.81	1.25	1.90	19.7	16.3	18.1	7.8
1979	2.25	0.50	1.21	2.32	8.3	14.7	14.4	8.6
1980	1.29	0.93	1.48	3.80	14.0	18.2	11.0	6.9
				Zinc				
1976	3.9	2.6	4.2	8.0	35.0	35.6	32.4	18.8
1977	4.0	3.7	4.0	12.2	45.9	24.5	12.7	4.7
1978	4.2	2.4	3.4	4.6	41.3	48.4	49.3	18.9
1979	4.0	2.0	3.4	3.9	14.8	59.2	40.4	14.5
1980	3.4	2.3	2.5	5.5	37.0	45.1	18.7	10.0

TABLE 44. SUMMARY OF WATER QUALITY DATA BY QUARTER AT MS-4

Quarter	1	2	3	4	1	2	3	4
Water Year	Flow (l/s)				pH			
1976	157.2	244.7	147.0	43.6	4.0	4.0	4.4	3.2
1977	194.3	109.3	59.8	14.2	4.1	4.4	3.7	2.9
1978	162.6	355.4	239.3	72.5	3.5	4.1	3.8	3.4
1979	75.0	478.6	181.2	66.3	3.6	3.9	3.7	3.3
1980	160.9	287.2	123.8	37.1	4.0	4.3	3.8	3.0
	Concentration (mg/l)				Load (kg/d)			
	Acidity							
1976	83	67	62	315	1127	1417	787	1187
1977	112	84	171	621	1880	793	884	762
1978	198	93	131	214	2782	2856	2708	1340
1979	191	140	292	200	1238	5789	4571	1146
1980	121	74	134	381	1682	1837	1433	1221
	Sulfate							
1976	187	123	141	483	2540	2600	1791	1819
1977	167	144	288	966	2804	1360	1488	1185
1978	179	116	212	400	2515	3562	4384	2506
1979	319	121	168	166	2067	5003	2630	951
1980	178	117	200	525	2474	2903	2139	1682
	Copper							
1976	0.5	0.5	0.6	2.1	7.2	10.4	8.1	7.9
1977	1.1	0.6	1.1	4.3	18.5	5.5	5.7	5.3
1978	1.8	0.8	0.9	1.1	25.3	24.9	18.4	6.9
1979	0.9	0.6	0.7	1.0	6.0	23.2	11.0	5.5
1980	0.6	0.5	0.5	1.5	8.3	12.4	5.3	4.8
	Iron							
1976	24	16	20	87	331	340	253	327
1977	37	26	37	128	613	244	469	157
1978	43	18	29	33	600	559	606	207
1979	37	18	17	30	242	736	269	172
1980	16	20	20	60	222	496	214	192

(continued)

TABLE 44. (continued)

Quarter	1	2	3	4	1	2	3	4
Water Year	Concentration (mg/l)				Load (kg/d)			
				Lead				
1976	0.023	0.027	0.085	0.121	0.3	0.6	1.1	0.5
1977	0.170	0.039	0.085	0.203	2.9	0.4	0.4	0.2
1978	0.070	0.109	0.053	0.064	1.0	3.3	1.1	0.4
1979	0.039	0.048	0.039	0.157	0.3	2.0	0.6	0.9
1980	0.014	0.033	0.013	0.092	0.2	0.8	0.2	0.3
				Manganese				
1976	1.6	1.0	1.4	4.1	21.1	20.0	17.4	15.3
1977	1.6	1.4	1.8	5.6	27.5	13.2	9.3	6.8
1978	1.8	1.2	1.4	2.1	25.4	26.9	29.6	13.0
1979	2.2	0.8	1.5	2.3	14.2	32.5	22.9	13.1
1980	1.3	1.0	1.5	3.8	18.1	24.8	16.0	12.2
				Zinc				
1976	3.6	2.7	3.4	9.2	49	57	43	35
1977	5.8	4.0	6.0	16.6	97	38	31	20
1978	7.0	3.6	4.5	7.6	98	111	93	48
1979	5.8	2.7	3.6	4.8	38	112	56	28
1980	4.3	2.8	2.9	7.8	60	69	31	25

TABLE 45. AVERAGE CONCENTRATIONS BY QUARTER AT MS-5 (mg/1)

Water Year & Quarter	pH	Acidity	SO_4	Cu	Fe	Pb	Mn	Zn
1976								
1	3.6	111	197	0.8	24	0.04	1.3	3.4
2	3.7	69	117	0.6	14	0.03	0.9	2.3
3	3.6	112	120	0.7	18	0.07	1.3	3.2
4	2.9	390	523	3.0	78	0.19	3.8	9.4
1977								
1	3.7	140	170	1.6	40	0.09	1.4	4.5
2	4.0	88	143	0.8	24	0.04	1.3	3.6
3	3.3	184	271	1.1	29	0.09	2.2	4.7
4	2.6	912	1346	9.7	143	0.28	6.1	2.1
1978								
1[a] 2	3.3	259	273	3.6	59	0.08	1.9	7.5
3	3.7	123	188	0.9	22	0.06	1.3	3.9
4	3.3	175	340	1.2	27	0.07	1.6	4.7
1979								
1	3.2	225	344	1.4	33	0.06	2.0	5.5
2	3.6	243	105	0.7	13	0.07	0.7	2.4
3	3.4	235	107	0.8	18	0.02	1.4	2.9
4	3.0	245	141	1.8	34	0.11	2.3	4.8

(continued)

TABLE 45. (continued)

Water Year & Quarter	pH	Acidity	SO_4	Cu	Fe	Pb	Mn	Zn
1980								
1	3.7	118	170	0.8	28	0.03	1.2	3.5
2[a]								
3	3.6	121	192	0.6	15	0.04	1.4	2.5
4	2.8	409	622	2.6	38	0.14	4.0	7.9

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[a] No sample collections this quarter.

Figures 57-72 show plots of pH and selected concentrations at various stream stations with MS-1 shown as control on each plot. The dramatic increases in the concentrations and associated drops in pH during the summers of 1976 and 1977 reflect the extreme low flows caused by the severe droughts of those years. The difference in amplitude of the peaks gives a good indication of the relative severity of the two droughts. Some of the extremely low concentration values result from samples being taken on high-flow days. Again, there appears to be little overall improvement in the AMD problem since reclamation began.

The plots shown in Figures 73-84 depict loads in kilograms per day for key parameters computed from the semi-monthly concentration data and the instantaneous flows recorded at the time of sample collection at the particular station. The computed loads are nearly always directly proportional to the magnitude of the flows. The pronounced peaks in the load plots usually reflect high flows that happened to be concurrent with sample collections, and the low points generally coincide with reduced flows during the late summer months. The dramatic rise in manganese and zinc loads at MS-3 in early 1976 is concurrent with the beginning of regrading at the Boyd Smith Site when all metal concentrations rose sharply.

Several sample collections were made on dates when there were significant increases in flow. Unfortunately, most of these collections were made sometime after the peak flow for a given storm event and none were made prior to the peak. Table 46 shows load, instantaneous flows, and the maximum flows recorded for the particular storm event at stations MS-2, MS-3 and MS-4 for six days on which high flows occurred. Only the sample collections of 11-29-76 and 1-24-79 were made near peak flow levels. The collections at MS-4 on these dates were approximately at peak levels and those at MS-2 and MS-3 occurred slightly past the peaks. The sample collection of 1-26-78 happened to occur on the same date as the highest flow ever recorded at MS-4 during the period of record which began in 1975. This was 19,852 liters per second (704 cfs) which was well above the instantaneous flow of 3766 liters per second (133 cfs) recorded at the time of sampling. The loadings on this date were also maximal.

The special study conducted by the University of Virginia showed that there are significant increases in loads and concentrations during the early stages of a storm that are not reflected in the quarterly averages or semi-monthly sampling data. This study revealed that loads usually reached a maximum level slightly before flows peaked, but there are several factors controlling the magnitude of the loads including the length of dry spell preceding the storm, temperature, and the amount of rainfall and duration. The reader is referred to pages 36 - 60 of this study in Appendix D for details of the rainstorm studies.

To portray stream loads during base flow conditions, a series of plots were generated with sample collection dates of all significant instantaneous flow increases above normal seasonal levels deleted. Plots of the base flow loads for MS-4 are shown in Figures 85-88. The criterion used for deletion of collection dates was based upon analysis of precipitation and discharge data to determine when the base flow of the stream was augmented by overland runoff or shallow subsurface flow after a rainstorm. Some of the deleted

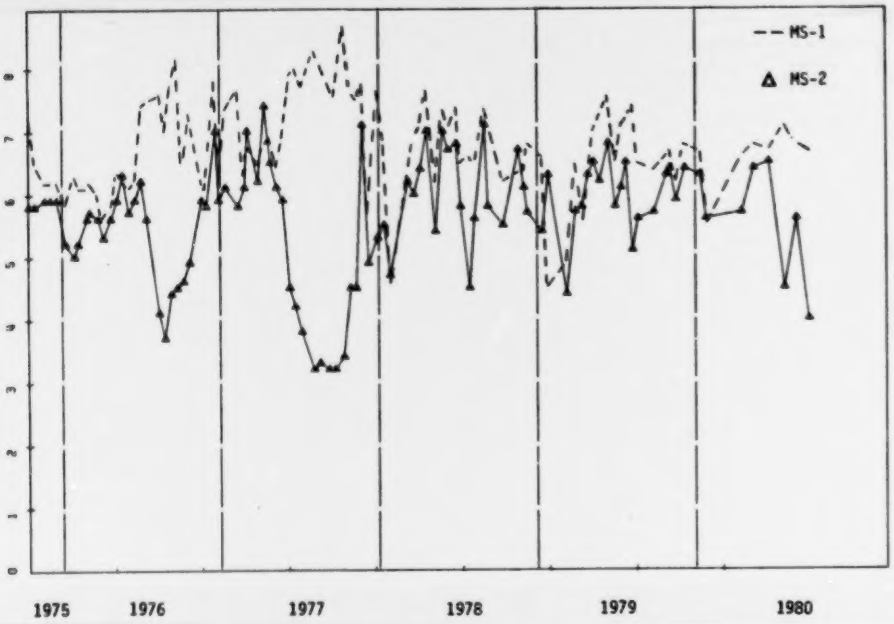

Figure 57. pH versus time in calendar years at MS-2 compared with control station.

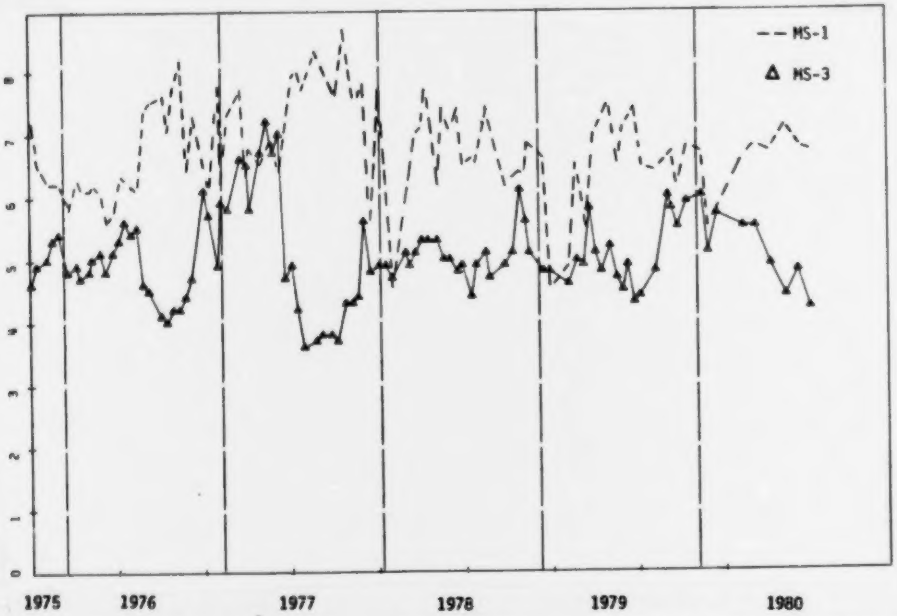

Figure 58. pH versus time in calendar years at MS-3 compared with control station.

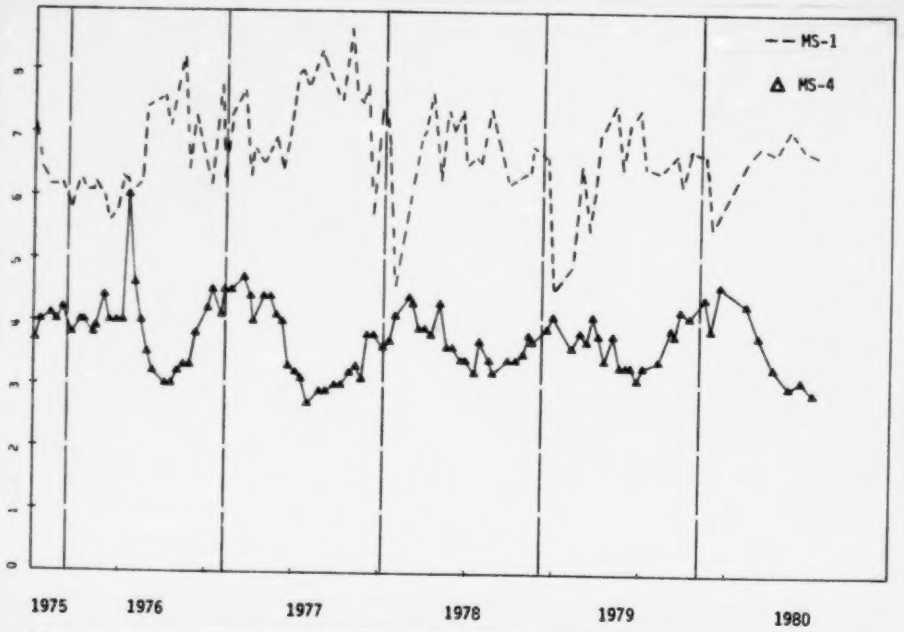

Figure 59. pH versus time in calendar years at MS-4 compared with control station.

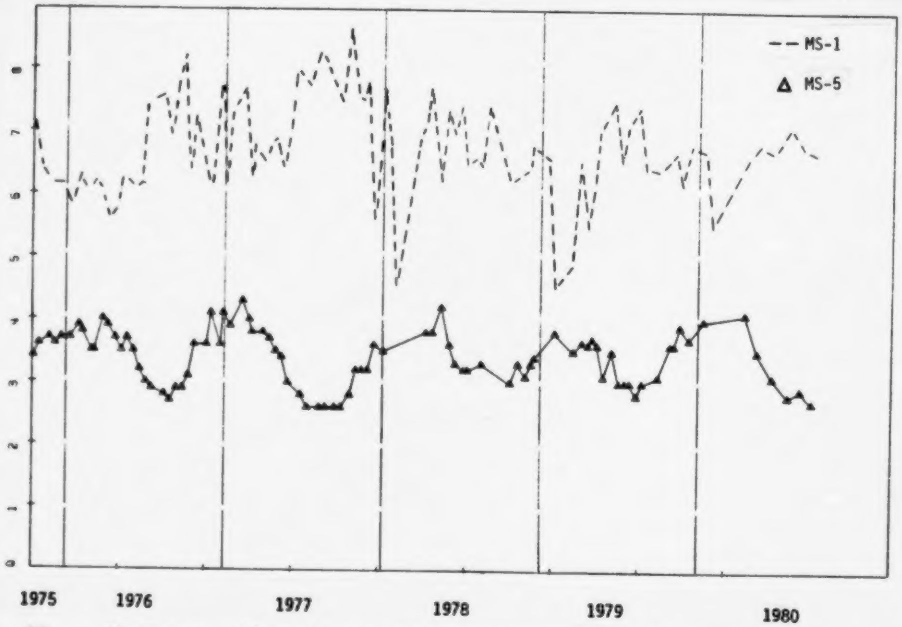

Figure 60. pH versus time in calendar years at MS-5 compared with control station.

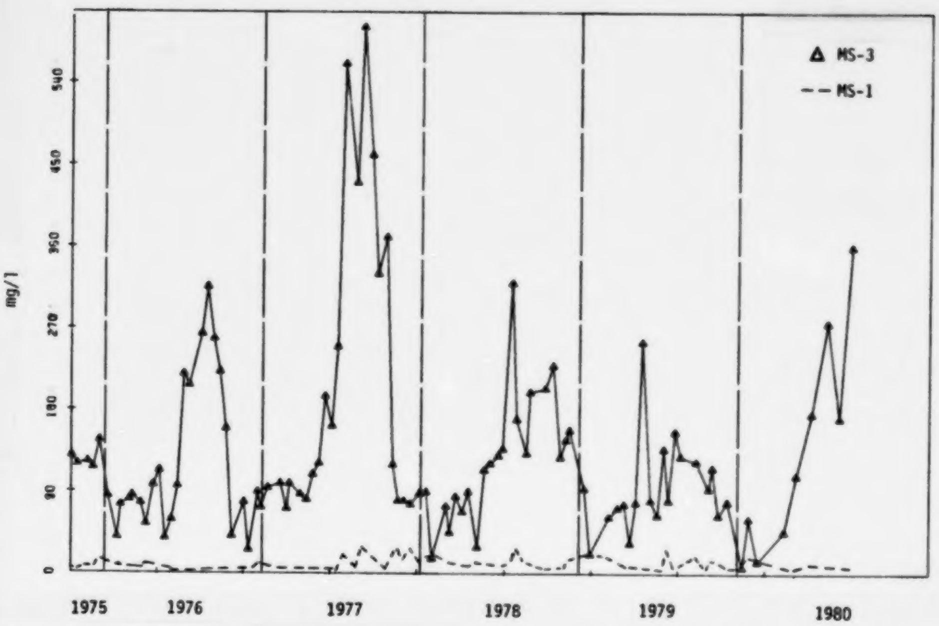

Figure 61. Sulfate concentrations versus time in calendar years at MS-3 compared with control station.

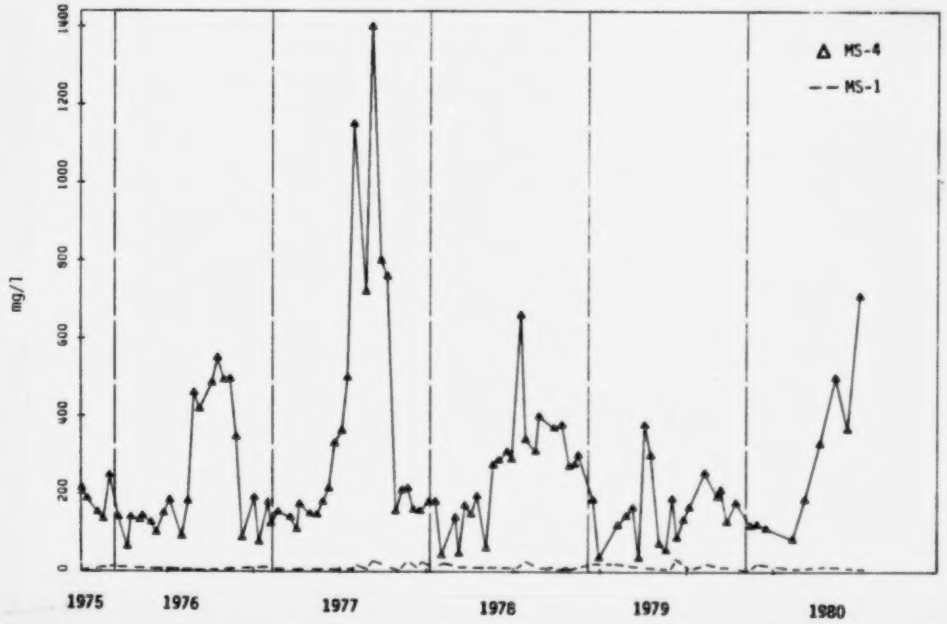

Figure 62. Sulfate concentrations versus time in calendar years at MS-4 compared with control station.

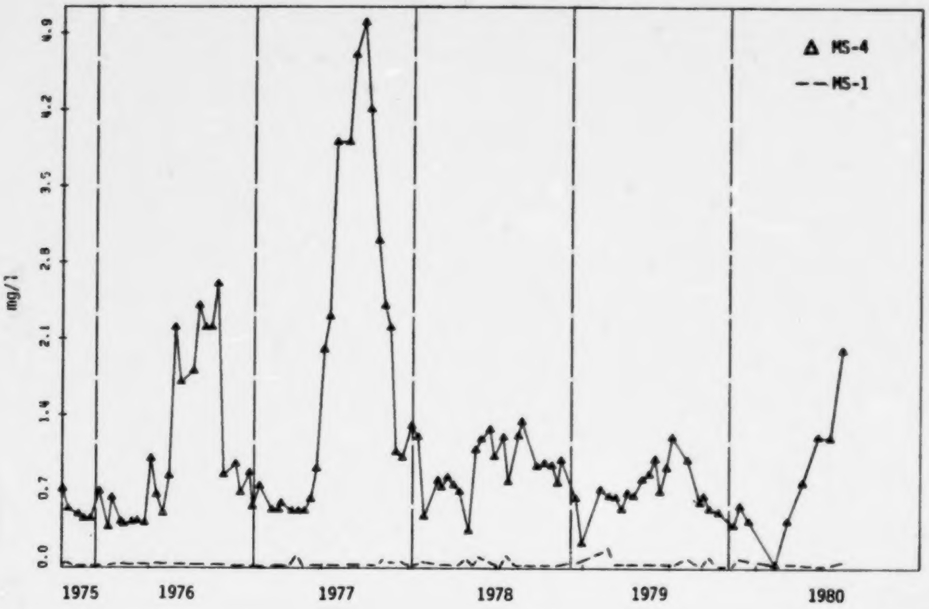

Figure 63. Copper concentrations versus time in calendar years at MS-4 compared with control station.

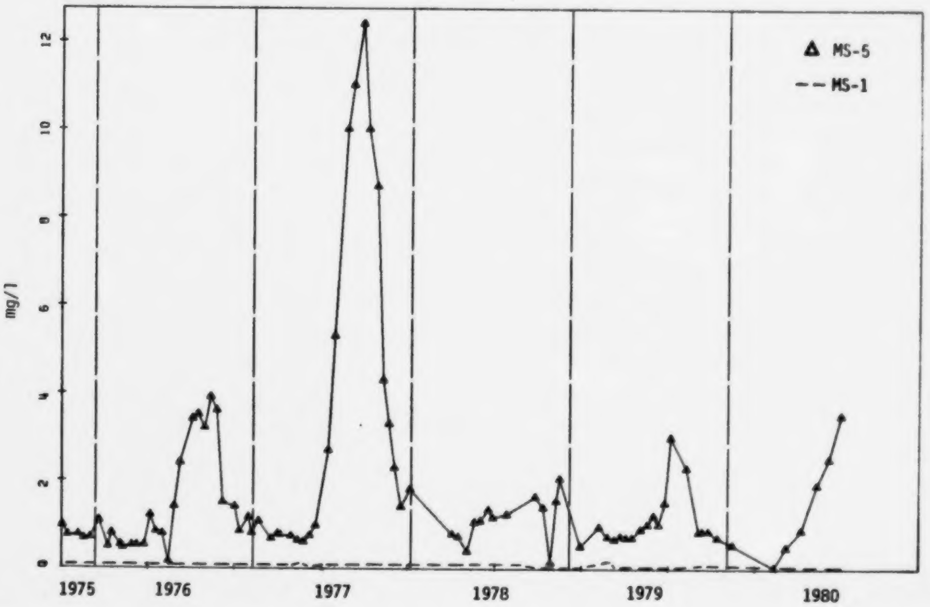

Figure 64. Copper concentrations versus time in calendar years at MS-5 compared with control station.

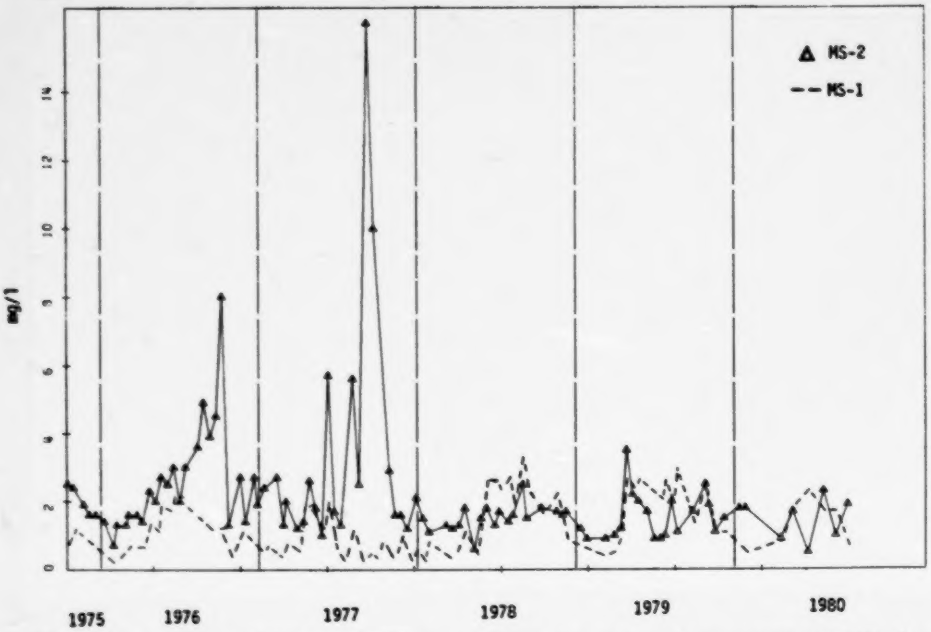

Figure 65. Iron concentrations versus time in calendar years at MS-2 compared with control station.

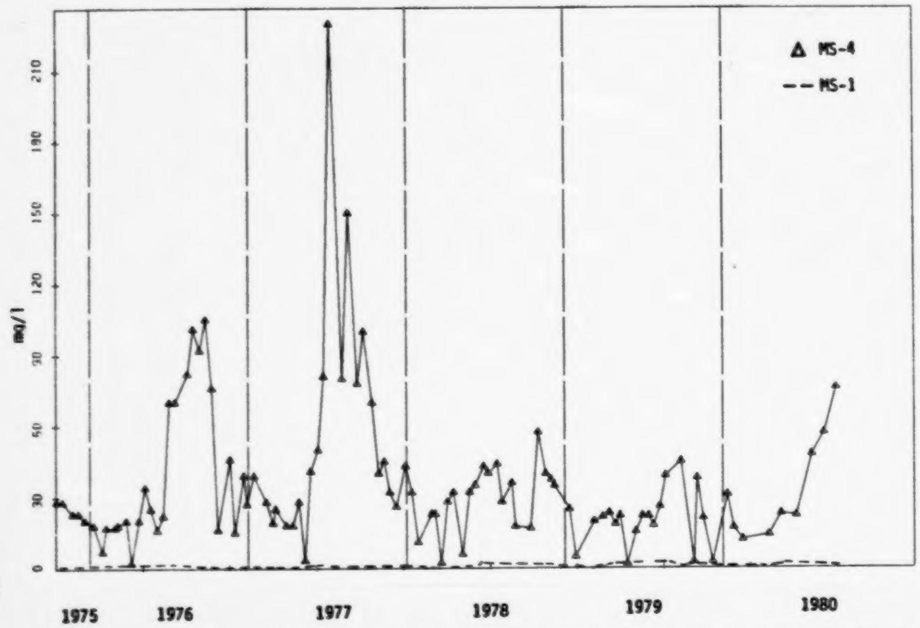

Figure 66. Iron concentrations versus time in calendar years at MS-4 compared with control station.

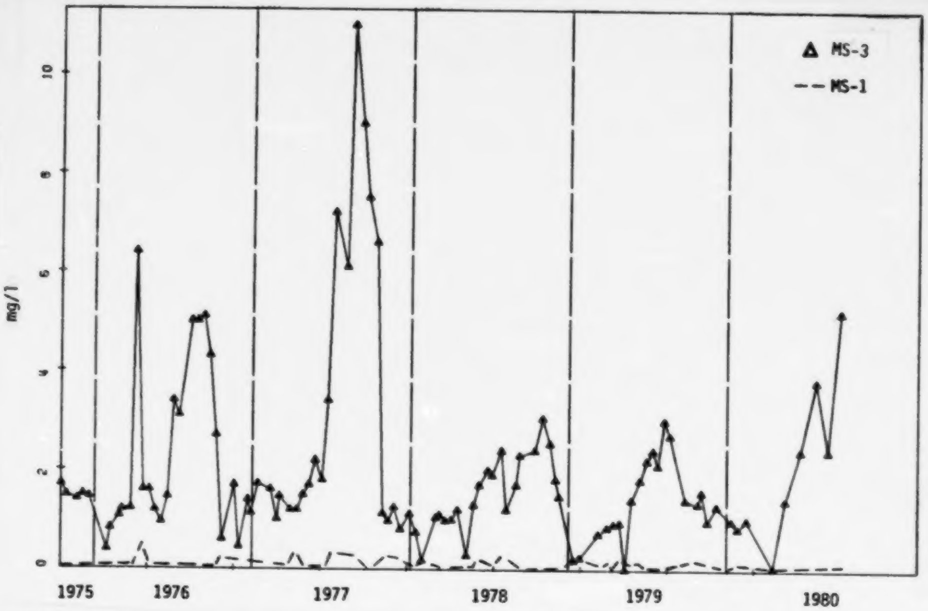

Figure 67. Manganese concentrations versus time in calendar years at MS-3 compared with control station.

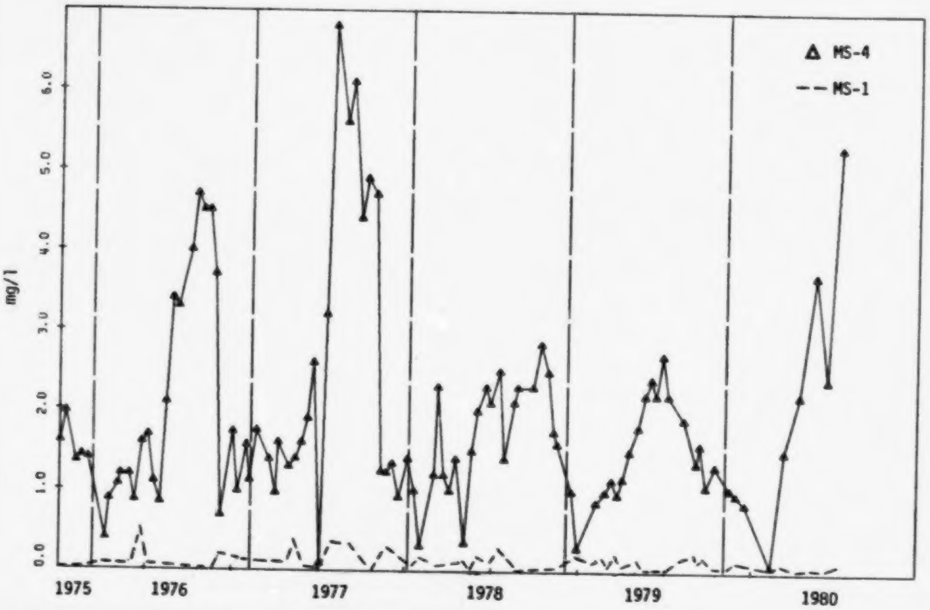

Figure 68. Manganese concentrations versus time in calendar years at MS-4 compared with control station.

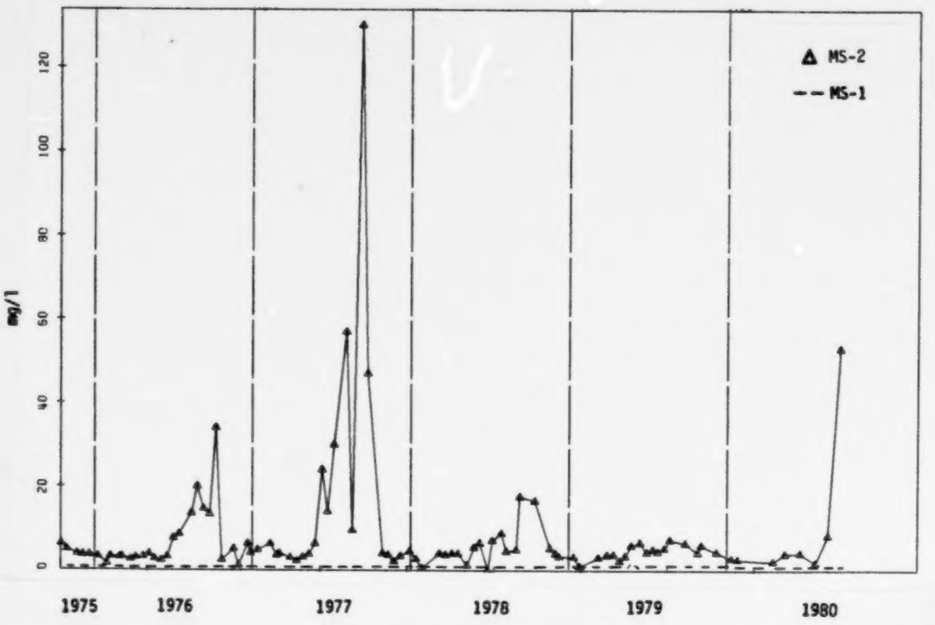

Figure 69. Zinc concentrations versus time in calendar years at MS-2 compared with control station.

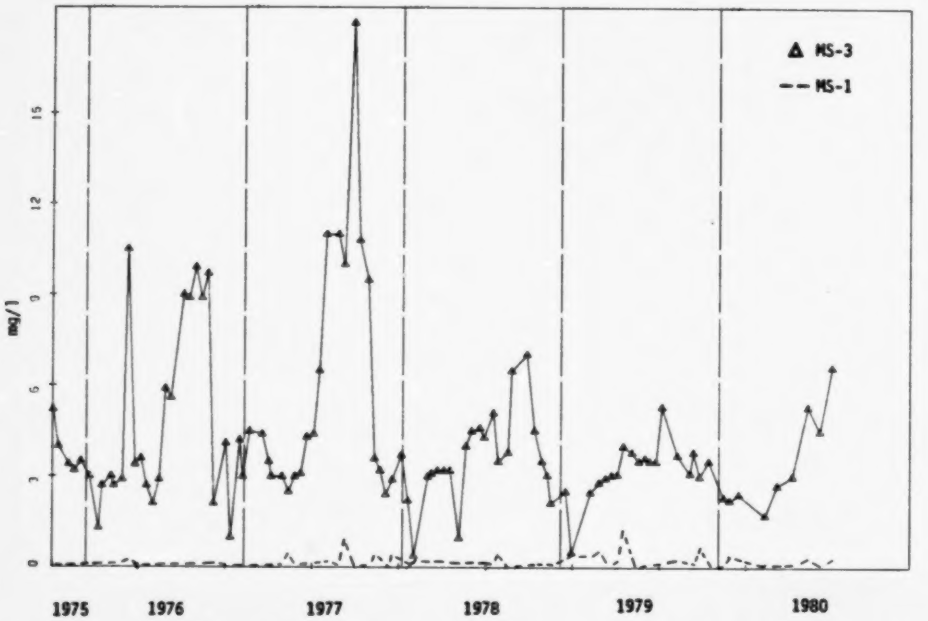

Figure 70. Zinc concentrations versus time in calendar years at MS-3 compared with control station.

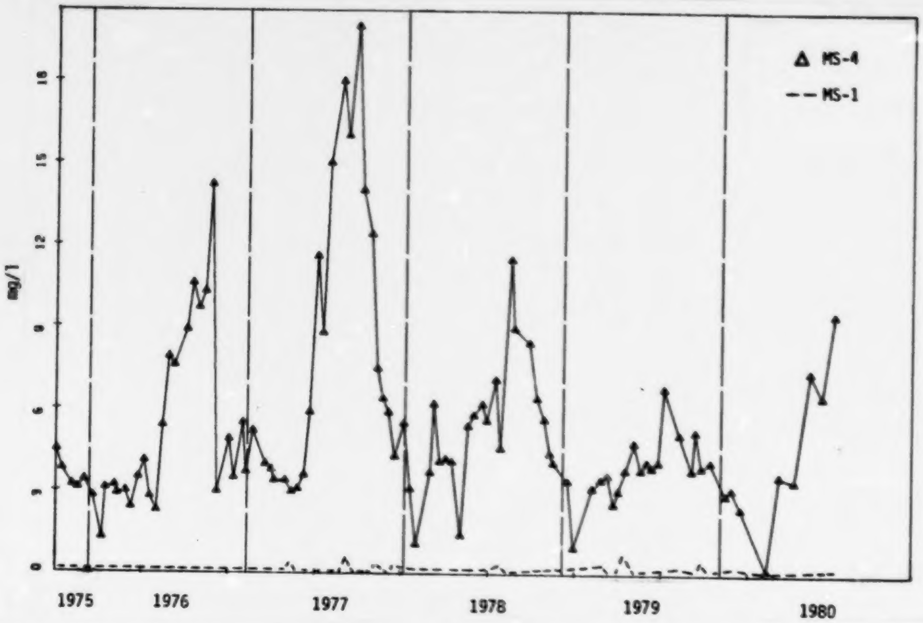

Figure 71. Zinc concentrations versus time in calendar years at MS-4 compared with control station.

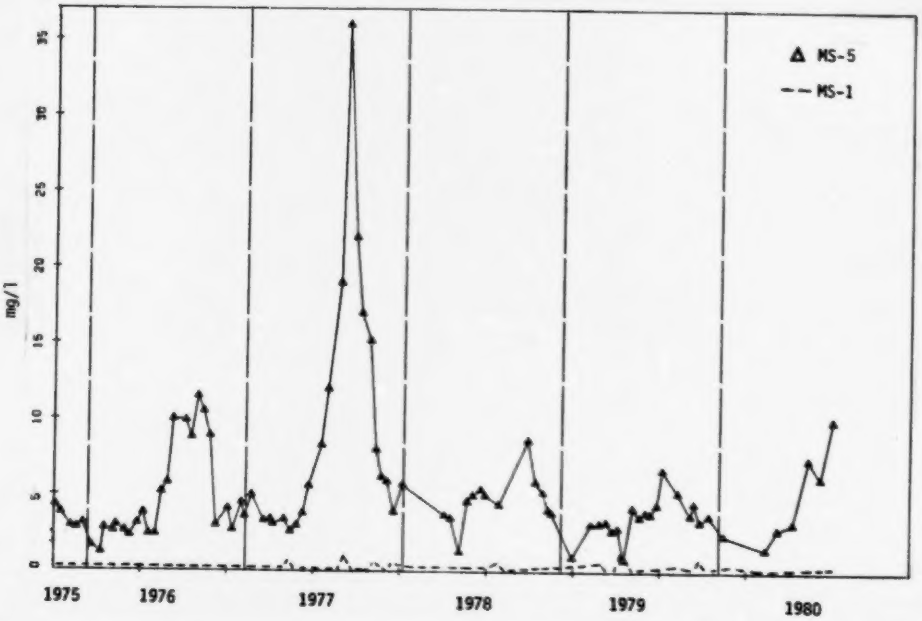

Figure 72. Zinc concentrations versus time in calendar years at MS-5 compared with control station.

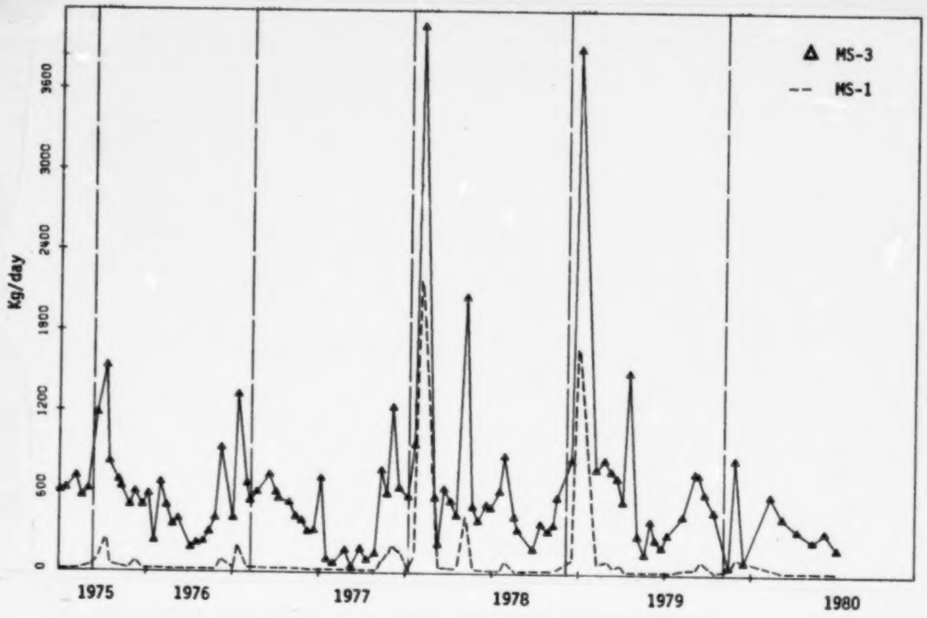

Figure 73. Sulfate loads based on instantaneous flows versus time in calendar years at MS-3 compared with control station.

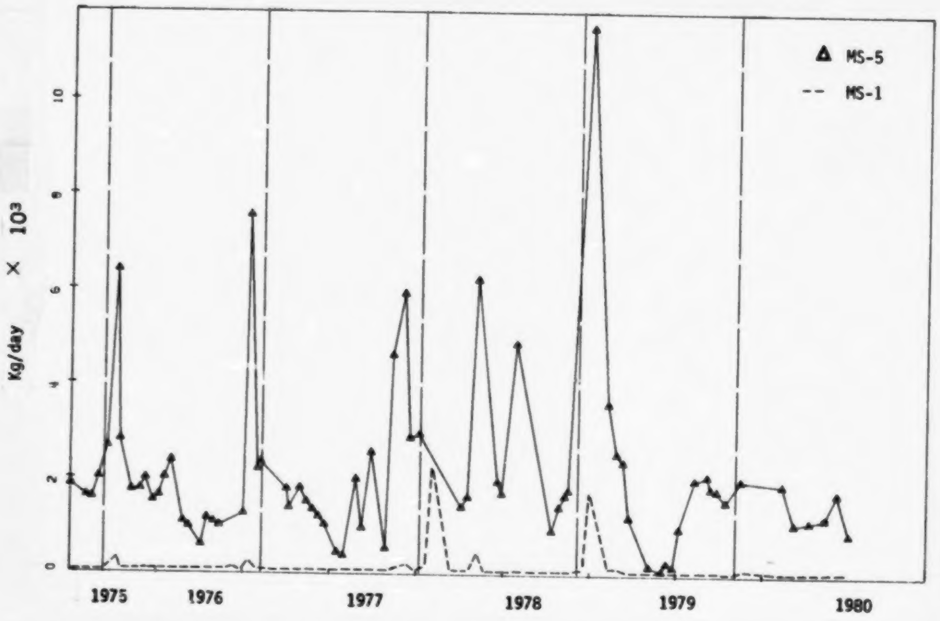

Figure 74. Sulfate loads based on instantaneous flows versus time in calendar years at MS-5 compared with control station.

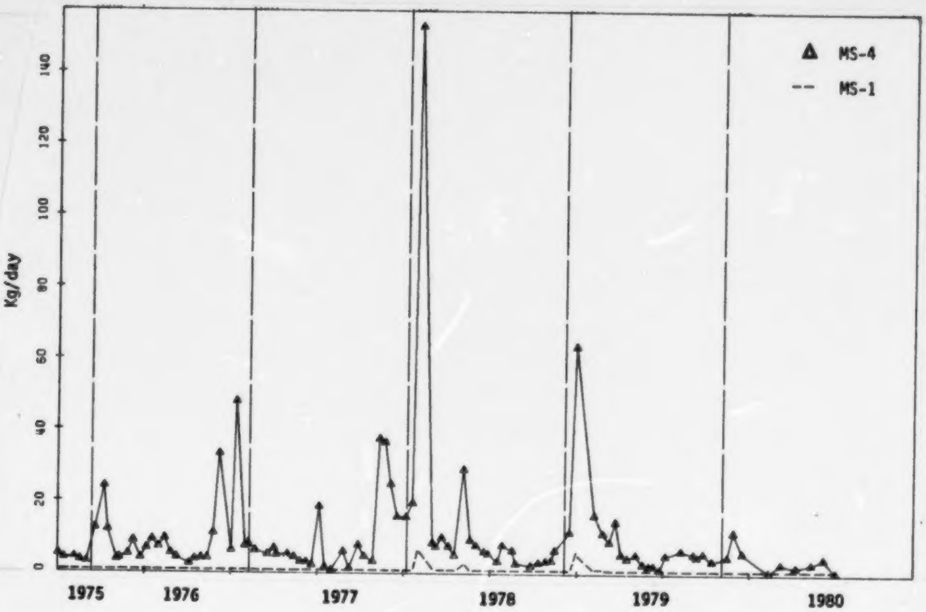

Figure 75. Copper loads based on instantaneous flows versus time in calendar years at MS-4 compared with control station.

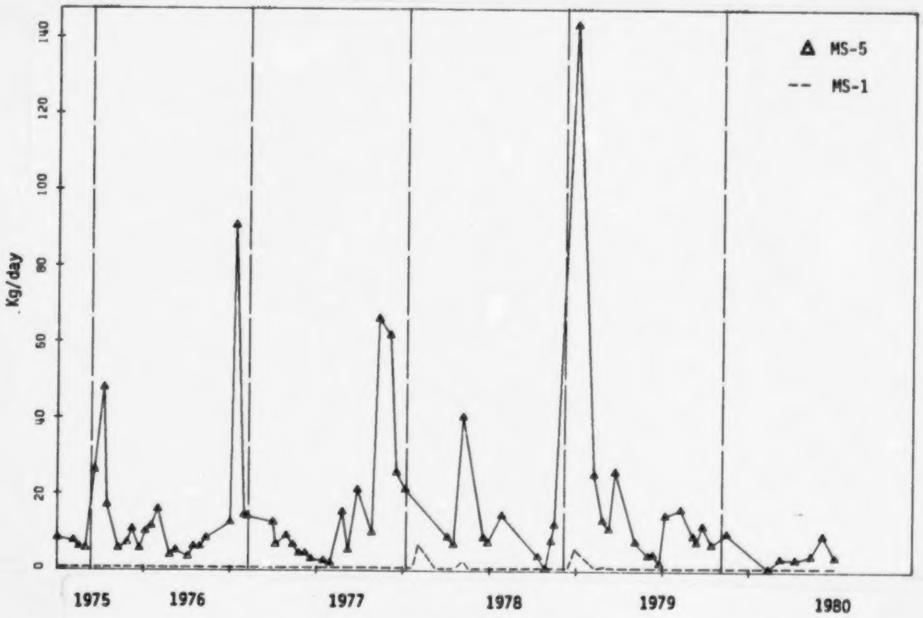

Figure 76. Copper loads based on instantaneous flows versus time in calendar years at MS-5 compared with control station.

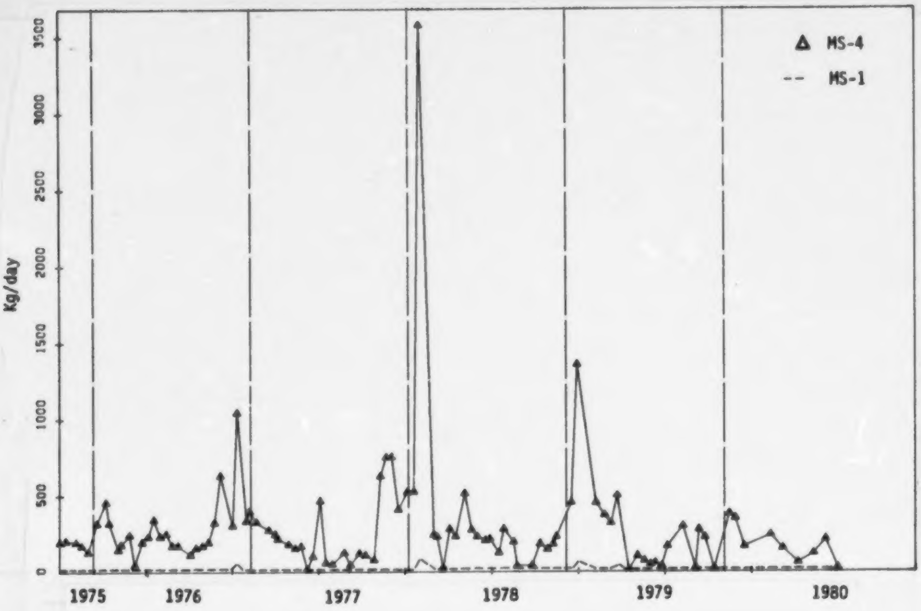

Figure 77. Iron loads based on instantaneous flows versus time in calendar years at MS-4 compared with control station.

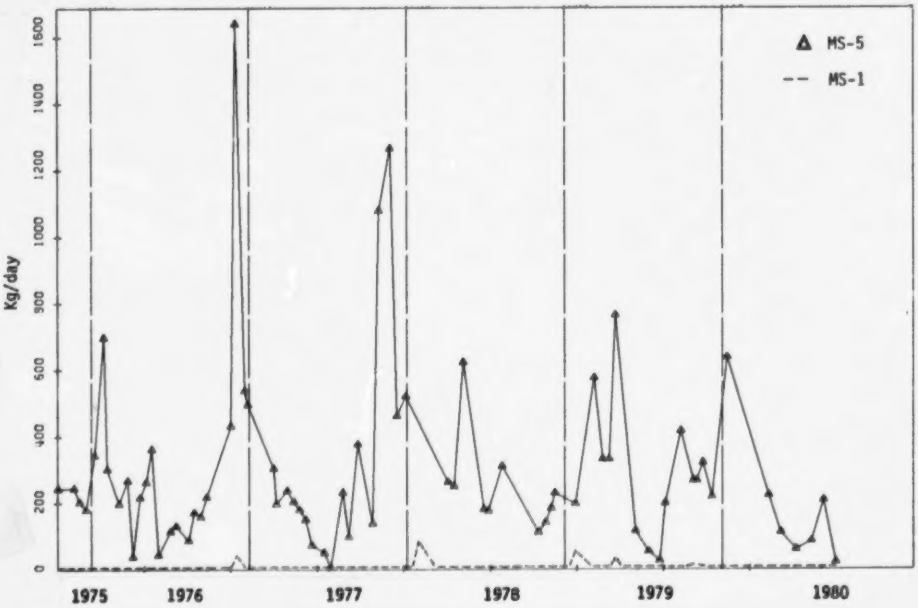

Figure 78. Iron loads based on instantaneous flows versus time in calendar years at MS-5 compared with control station.

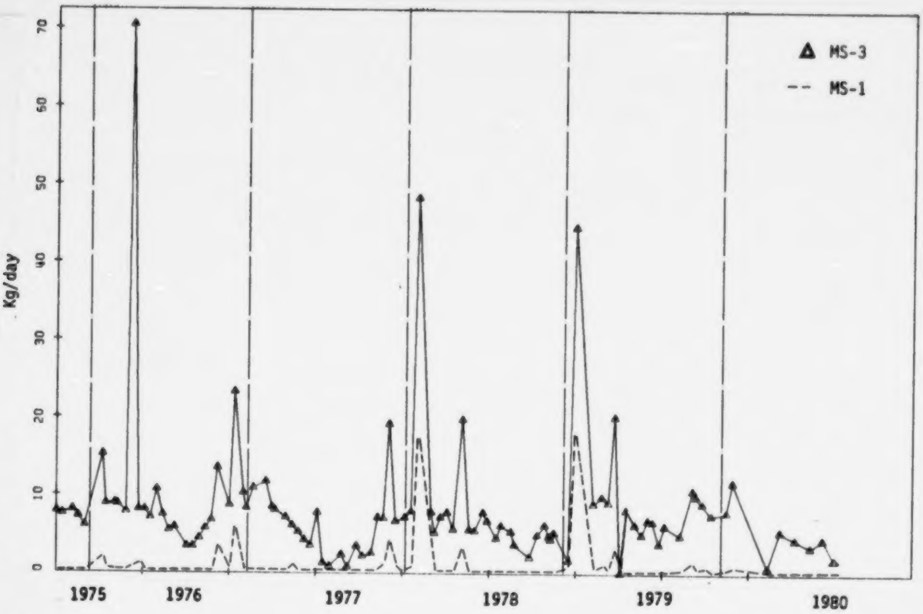

Figure 79. Manganese loads based on instantaneous flows versus time in calendar years at MS-3 compared with control station.

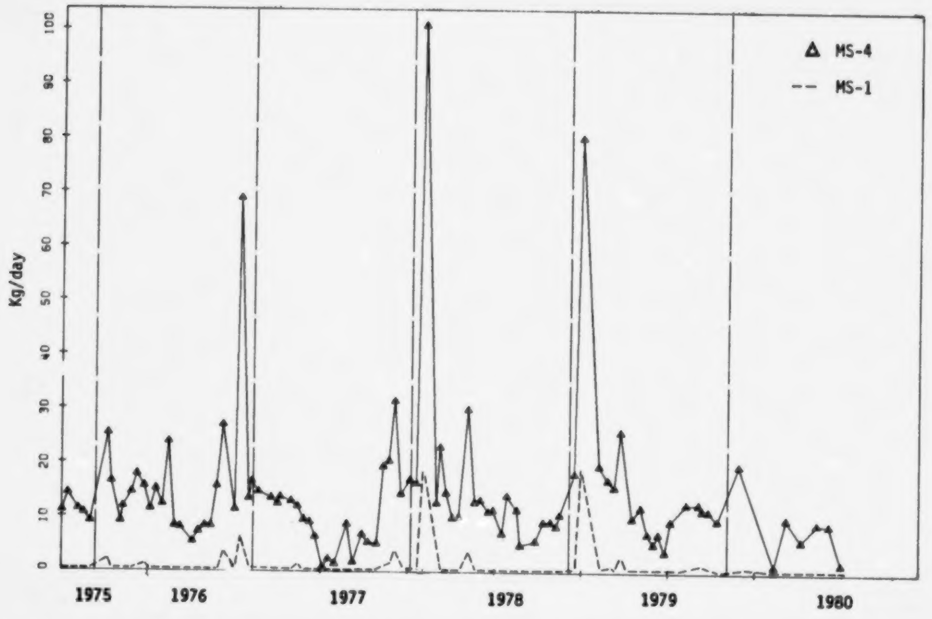

Figure 80. Manganese loads based on instantaneous flows versus time in calendar years at MS-4 compared with control station.

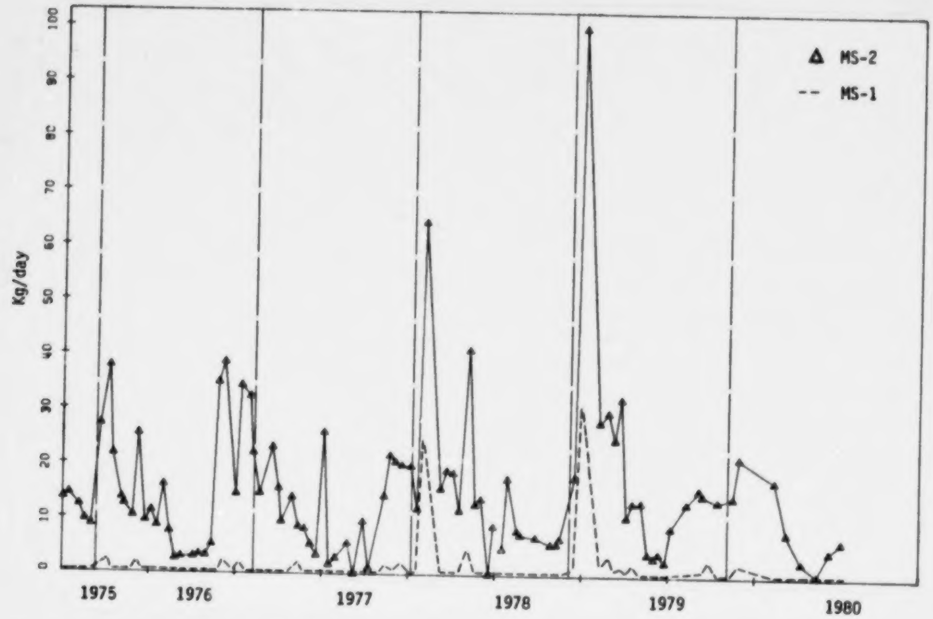

Figure 81. Zinc loads based on instantaneous flows versus time in calendar years at MS-2 compared with control station.

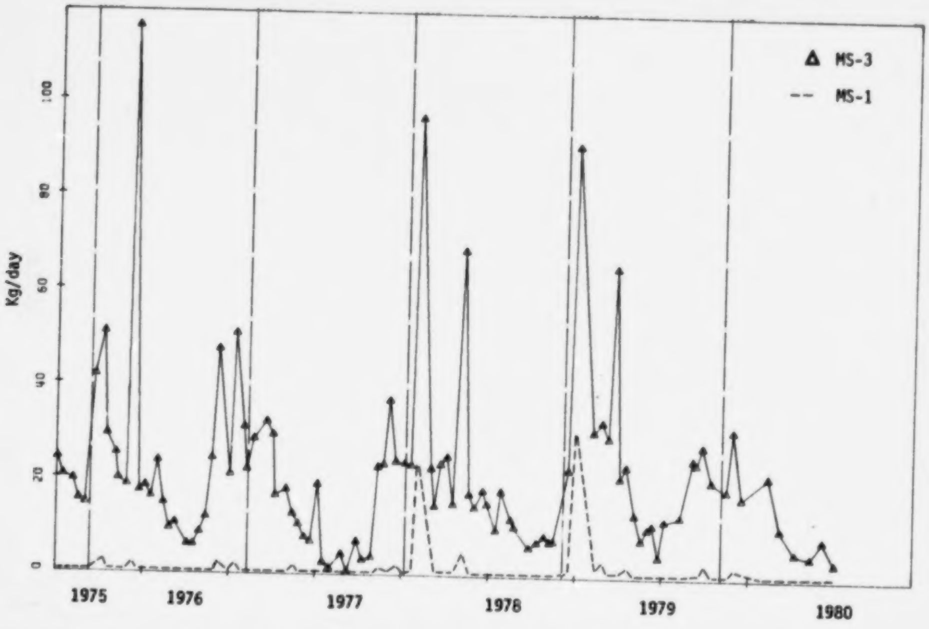

Figure 82. Zinc loads based on instantaneous flows versus time in calendar years at MS-3 compared with control station.

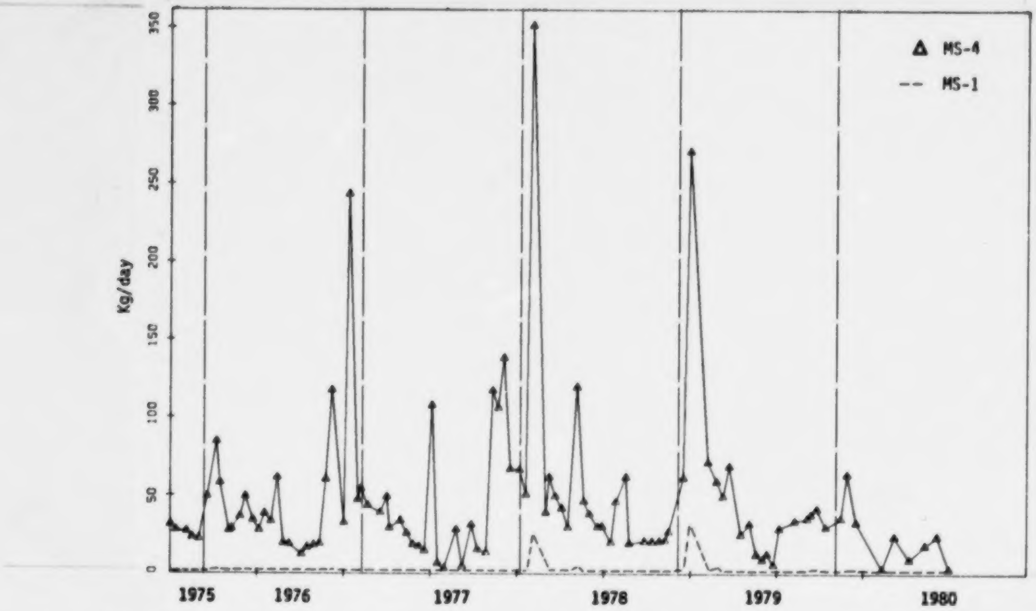

Figure 83. Zinc loads based on instantaneous flows versus time in calendar years at MS-4 compared with control station.

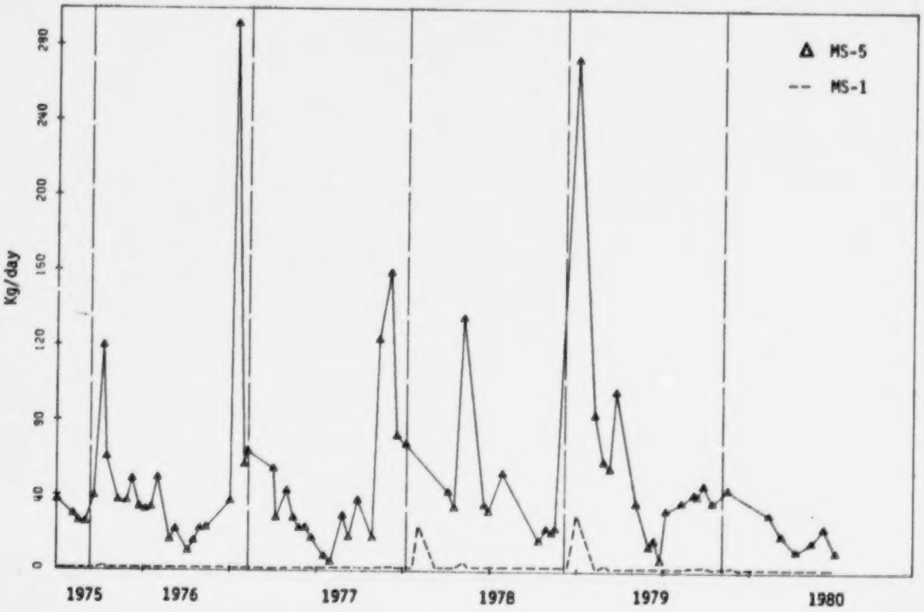

Figure 84. Zinc loads based on instantaneous flows versus time in calendar years at MS-5 compared with control station.

TABLE 46. LOAD VALUES FOR HIGH FLOW DAYS (Kg/d)[a]

Date	Max[b] Flow (l/s)	Hrs.[c]	Instantaneous[d] Flow (l/s)	SO_4	Cu	Fe	Pb	Mn	Zn
MS-2									
1-28-76	1388	17	292	948	2.3	20	0.4	7.8	44
10-21-76	4871	21	186	717	2.8	24	4.1	7.6	45
11-29-76	453	3	365	687	2.2	51	1.0	12.4	40
1-26-78	9346	9	1331	2795	8.0	146	1.7	26.6	75
5-09-78	1303	11	397	1031	4.8	24	0.6	9.1	48
1-24-79	1586	2	1246	3115	7.5	112	5.6	34.9	116
MS-3									
1-28-76	2294	16	453	1771	4.5	45	0.7	17.7	59
10-21-76	5551	20	262	1070	5.5	39	1.0	15.7	55
11-29-76	765	3	600	1531	4.8	96	3.4	27.0	59
1-26-78	10139	9	2945	4712	23.6	530	7.4	56.0	112
5-09-78	2804	11	821	2381	10.7	58	1.1	23.0	80
1-24-79	2577	2	2152	4519	10.8	194	8.0	51.7	106
MS-4									
1-28-76	3257	12	753	4715	27.9	527	2.5	29.4	98
10-21-76	8326	20	453	3915	38.5	729	3.7	31.3	136
11-29-76	793	0	804	6064	55.5	1206	38.1	79.6	282
1-26-78	19852	7.5	3766	15818	177.0	4143	137.1	116.8	407
5-09-78	2549	9.5	991	5947	33.7	595	3.5	34.7	139
1-24-79	3059	1	3200	11519	73.6	1568	31.7	92.8	313

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[a] To convert kg/day to lbs/day multiply by 2.205.

[b] Peak flow recorded this storm event; to convert liter/sec to cfs multiply by 0.0353.

[c] No. hours after peak flow that sample was collected.

[d] Instantaneous flow recorded at time sample was collected.

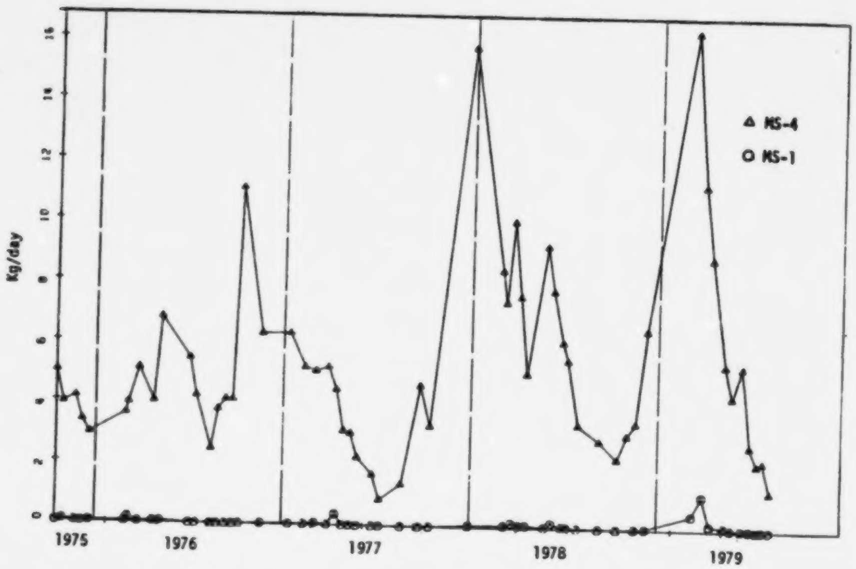

Figure 85. Copper loads computed from instantaneous flows under base flow conditions versus time in calendar years at MS-4 compared with control station.

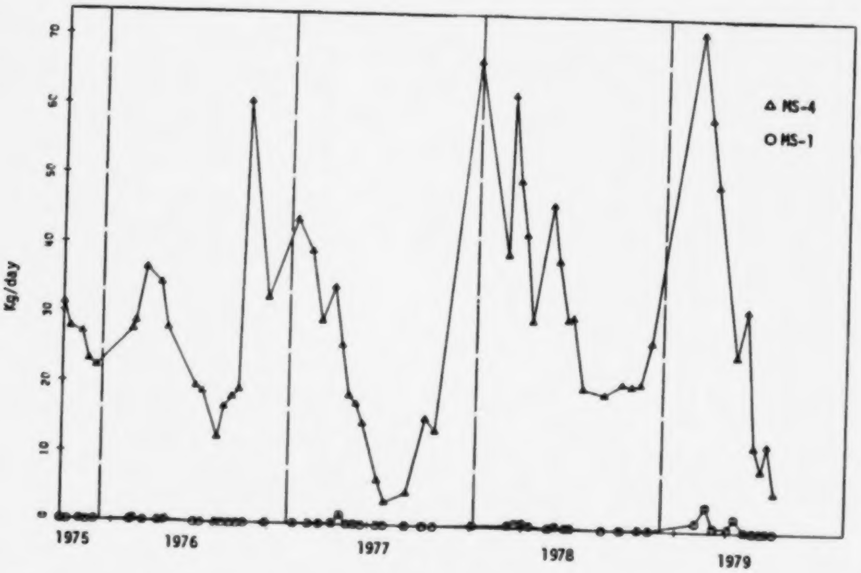

Figure 86. Zinc loads computed from instantaneous flows under base flow conditions versus time in calendar years at MS-4 compared with control station.

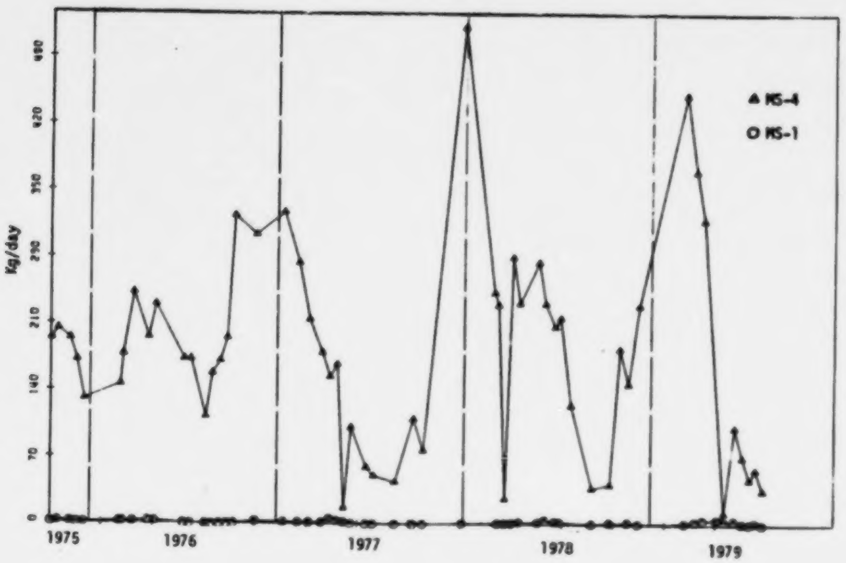

Figure 87. Iron loads computed from instantaneous flows under base flow conditions versus time in calendar years at MS-4 compared with control station.

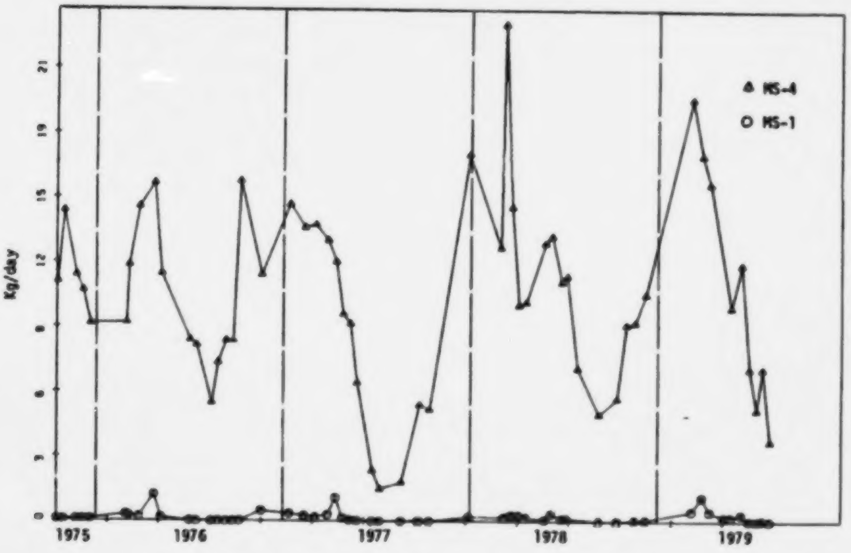

Figure 88. Manganese loads computed from instantaneous flows under base flow conditions versus time in calendar years at MS-4 compared with control station.

flows were low to moderate discharges following a dry spell, but most were higher than normal base flow. Approximately 30 per cent of the collection dates from October 1975 thru September 1979 were deleted. The instantaneous flows used in this portrayal averaged 64 liters per second (2.3 cfs) at MS-4. The base flow curves present a clearer seasonal pattern of loading with peaks generally reached in the fall and winter months and minimum loading during the summer.

The relative load contributions from each site can be deduced from the various means used to present the load data. It is obvious that loads increase as Contrary Creek passes each mine site, and apparently certain minerals are peculiar to each site. Without question the Sulphur Site contributes the major bulk of the AMD load as indicated by the dramatic increases in acidity, sulfate, iron, copper and lead at MS-4. Generally during periods of low flow in late summer and early fall there was about a sixteen-fold increase in acidity, eleven-fold increase in copper, nine-fold increase in iron, and thirty-fold increase in lead loading between MS-3 and MS-4 which bracket the Sulphur Site. On a year-round basis the zinc load increased about fifty times between MS-1 and MS-2 indicating that the Arminius Site is a major source of that metal, and the Boyd Smith Site appears to be the principal contributor of manganese. From the instantaneous flow data collected at MS-5 it is apparent that all pollutant loads increased in the reach of Contrary Creek between the Sulphur Site and Lake Anna where no reclamation work was done. In this section of the stream the bed is full of mine wastes washed from the upstream mine sites.

An overall comparison of the AMD loads for water year 1980 with loads from previous quarters when flows were of similar magnitude shows little change at MS-2 and MS-4 over the monitoring period, but there was a pronounced decrease in most metal loads at MS-3. There are undoubtedly many statistical analyses that could be made of the load data presented, but no further interpretation is attempted here.

Annual Complete Analyses

As stated earlier a complete analysis of additional parameters was conducted at all sampling stations at least once annually. The results of these analyses for the stream stations with flow data are presented in Tables 47-49. Of the additional metals analyzed, only cadmium was found to equal or slightly exceed the SWCB limit of 0.01 mg/l on a few occasions in the affected reach of the stream. The total and dissolved solids and specific conductance values reflect the same trend in concentrations as the regular metals data.

The regular semi-monthly sampling included fecal coliform and BOD_5 analyses to determine if any effects of wastewater sludge used in the project could be detected in the stream and lake samples. Fecal coliform counts virtually never exceeded 100 organisms per 100 ml of sample at any stream station during the five-year period of monitoring.* The BOD_5 usually ranged from 1 to 2 mg/l

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* The bacterial standard for non-shellfish waters in Virginia is 200 organisms per 100 ml of sample.

TABLE 47. WATER QUALITY DATA- ADDITIONAL METALS INCLUDED IN COMPLETE ANALYSES (mg/l)[a]

Station	Date	Flow (l/s)	pH	Specific Conductance (µmhos/cm)	Al	As	Cd	Cr	Hg	K	Na
MS-1	10-27-75	22.9	6.5	47	0.5-	0.003-	0.01-	0.01-	0.0005-	0.01-	3.3
	5-19-76	30.9	6.2	44	0.2-	0.002-	0.01-	0.01-	0.0005-	0.01-	1-
	5-24-77	5.1	6.9	60	0.5	0.002-	0.01-	0.01-	0.0005-	1.8	6.0
	5-25-78	17.3	7.4	49	0.6	0.002-	0.01-	0.01	0.0005-	1.9	2.0
	6-12-79	22.7	7.4	59	1.0	0.001-	0.01-	0.01-	0.0003-	0.8	6.0
	5-14-80	19.3	6.8	63	2.0	0.001-	0.01-	0.01	0.0003-	0.9	5.0
MS-2	10-27-75	34.0	5.8	170	4.5	0.003-	0.02	0.01-	0.0005-	0.1-	3.5
	5-19-76	36.8	6.3	120	0.7	0.002-	0.01-	0.01-	0.0005-	0.1-	1.0
	5-24-77	6.2	5.9	350	0.6	0.002-	0.01	0.01-	0.0005-	2.2	5.0
	5-25-78	27.5	7.0	180	1.0	0.002-	0.02	0.01-	0.0005-	2.2	4.0
	6-12-79	25.5	6.8	174	0.2	0.001-	0.01-	0.01-	0.0003-	0.5	4.0
	5-14-80	23.5	6.4	195	4.0	0.001-	0.01-	0.01	0.0003-	1.3	6.0
MS-3	10-27-75	59.5	4.9	240	2.4	0.003-	0.01-	0.01-	0.0005-	0.1-	4.2
	5-19-76	69.4	5.6	156	1.2	0.002-	0.01-	0.01-	0.0005-	0.1-	1-
	5-24-77	18.7	4.7	365	1.9	0.002-	0.01	0.01-	0.0005-	2.3	4.0
	5-25-78	50.1	5.0	252	1.6	0.002-	0.02	0.01	0.0005-	2.2	1.0
	6-12-79	40.5	5.2	267	1.8	0.001-	0.01-	0.01-	0.0003-	1.6	6.0
	5-14-80	45.3	5.5	288	1.0	0.001-	0.01-	0.01	0.0003-	1.3	5.0
MS-4	10-27-75	84.4	4.0	390	6.3	0.006	0.02	0.01-	0.0005-	0.5	7.8
	5-19-76	158.6	6.0	56	3.5	0.002-	0.01-	0.01-	0.0005-	0.1	1-
	5-24-77	28.6	3.3	680	15.0	0.002	0.02	0.01-	0.0005-	2.6	4.0
	5-25-78	99.4	3.6	583	8.6	0.002-	0.02	0.01	0.0005-	2.4	
	6-12-79	76.5	3.8	568	7.3	0.002	0.01-	0.02	0.0003-	1.0	4.0
	5-14-80	76.5	3.8	447	5.0	0.003	0.01-	0.01	0.0003-	1.3	7.0
MS-5	10-27-75		3.6	630	6.4	0.006	0.01-	0.01-	0.0005-	0.1-	4.3
	5-19-76	160.9	3.7	330	3.7	0.002-	0.01-	0.01-	0.0005-	0.1-	1-
	5-24-77	35.7	3.0	820	20.0	0.002-	0.01	0.01-	0.0005-	2.9	8.0
	5-25-78		3.6	589	7.6	0.002-	0.02	0.01	0.0005-	2.5	4.0
	6-12-79	100.0	3.5	618	7.0	0.001	0.01-	0.01	0.0003-	1.0	4.0
	5-14-80	80.1	3.5	476	5.0	0.002	0.01-	0.01	0.0003-	1.4	6.0

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[a] A (-) sign indicates that the concentration was below the incidated level of detection.

TABLE 48. WATER QUALITY DATA - SOLIDS, SPECIFIC CONDUCTANCE, TURBIDITY[a]

Station	Date	Flow (l/s)	Total Solids (mg/l) (Total)	Total Solids (mg/l) (Vol)	Total Solids (mg/l) (Fix)	Suspended Solids (mg/l) (Total)	Suspended Solids (mg/l) (Vol)	Suspended Solids (mg/l) (Fix)	Total Dissolved Solids (mg/l)	Specific Conductance (μmhos/cm)	Turbidity (NTU)
MS-1	10-27-75	22.9	68	37	31	0	0	0	68	47	3.5
	5-19-76	30.9	110	58	52	2	2	0	108	44	5.0
	5-24-77	5.1	739	412	327	8	8	0	731	60	3.2
	5-25-78	17.3	64	20	44	12	5	7	52	49	6.7
	6-12-79	22.7	61	16	45	2	1	1	59	59	6.1
	5-14-80	19.3	80	28	52	12	5	7	68	63	7.0
MS-2	10-27-75	34.0	176	21	155	4	2	2	172	170	7.3
	5-19-76	36.8	127	39	88	30	16	14	97	120	7.5
	5-24-77	6.2	289	74	215	1	1	0	288	350	3.1
	5-25-78	27.5	151	25	126	14	5	9	137	180	7.6
	6-12-79	25.5	168	31	137	8	4	4	160	174	6.2
	5-14-80	23.5	166	46	120	17	8	9	149	195	7.0
MS-3	10-27-75	59.5	254	78	176	6	2	4	248	240	5.9
	5-19-76	69.4	204	65	139	14	6	8	190	156	7.2
	5-24-77	18.7	348	136	212	3	3	0	345	365	1.1
	5-25-78	50.1	227	48	179	8	1	7	219	252	6.4
	6-12-79	40.5	242	45	197	7	0	7	235	267	6.2
	5-14-80	45.3	245	61	184	24	11	13	221	288	8.8
MS-4	10-27-75	84.4	368	79	289	14	6	8	354	390	4.0
	5-19-76	158.6	85	43	42	20	14	6	65	56	5.2
	5-24-77	28.6	576	173	403	17	6	11	559	680	1.6
	5-25-78	99.4	511	149	362	31	5	26	470	583	12.0
	6-12-79	76.5	458	102	356	9	3	6	449	568	9.7
	5-14-80	76.5	357	71	286	14	7	7	343	447	8.3
MS-5	10-27-75		392	85	307	10	4	6	382	630	1.3
	5-19-76	160.9	299	91	208	26	4	22	273	330	10.0
	5-24-77	35.7	508	191	317	1-	1-	1-	508	820	0.4
	5-25-78		485	179	306	23	5	18	462	589	7.9
	6-12-79	100.0	434	123	311	2	1	1	432	618	2.6
	5-14-80	80.1	351	91	260	9	5	4	342	476	1.0

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[a] A (-) sign indicates that the concentration was below the indicated level of detection.

TABLE 49. WATER QUALITY DATA - MISCELLANEOUS PARAMETERS (mg/1)

Station	Date	Flow (1/s)	Ca	Mg	Hardness ($CaCO_3$)	Cl	F	Cyanide
MS-1	10-27-75	22.9	4	2.3	22	3	0.1-	
	5-19-76	30.9	4	2.3	24	4	0.1-	0.01-
	5-24-77	5.1	6	3.0	28	2		0.01-
	5-25-78	17.3	5	2.5	18	3		0.01-
	6-12-79	22.7	14	8.3	26	1		
	5-14-80	19.3	5	2.4	24	2	0.1-	
MS-2	10-27-75	34.0	15	8.0	54	3	0.5	
	5-19-76	36.8	11	5.5	44	3	0.0	0.01-
	5-24-77	6.2	28	12.4	100	3		0.01-
	5-25-78	27.5	14	7.9	62	2		0.01-
	6-12-79	25.5	4	2.5	81	2		
	5-14-80	23.5	15	7.5	68	2	0.1	
MS-3	10-27-75	59.5	21	12.7	116	3	0.1	
	5-19-76	69.4	16	9.5	79	5	0.1	0.01-
	5-24-77	18.7	37	14.0	134	3		0.01-
	5-25-78	50.1	18	11.0	78	3		0.01-
	6-12-79	40.5	19	12.0	103	2		
	5-14-80	45.3	22	12.0	100	2	0.1	
MS-4	10-27-75	84.4	18	13.6	116	3	0.3	
	5-19-76	158.6	15	9.8	26	4	0.1-	0.01-
	5-24-77	28.6	31	16.0	100	1		0.01-
	5-25-78	99.4	20	14.0	68	4		0.01-
	6-12-79	76.5	21	21.0	95	3		
	5-14-80	76.5	20	12.0	93	2	0.3	
MS-5	10-27-75		16	12.4	120	2	0.24	
	5-19-76	160.9	13	9.0	60	4	0.16	0.01-
	5-24-77	35.7	26	13.0	110	3		0.01-
	5-25-78		17	13.0	64	4		0.01-
	6-12-79	100.0	19	13.4	86	3		
	5-14-80	80.1	17	13.0	82	2	0.2	

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[a] A (-) sign indicates that the concentration was below the indicated level of detection.

at MS-2 and MS-3 which was generally the same as background at MS-1. At MS-4 the BOD_5 ranged from 1 to 2 mg/l during the first year of monitoring, but increased to a range of around 3 to 6 mg/l over the next four years with a few higher values recorded in the fall of 1977. BOD_5 at MS-5 closely paralleled that at MS-4 with values generally being 1 mg/l or less during the first year and ranging from 2 to 5 mg/l the last four years. The slight increases in BOD_5 at MS-4 and MS-5 from late 1976 until 1980 presumably result from the large volumes of sludge that have been incorporated at the reclaimed mine sites. For a further check on the effects of sludge, nutrients and other oxygen demand parameters were included in the annual complete water analyses which are shown in Table 50. Composite monthly analyses of the Blue Plains STP sludge provided by the District of Columbia are shown in Table 51. For a comparison of sludge analyses conducted by the DCLS in 1977, see Table 9 on Page 46. On the basis of all analyses performed, it is believed that the use of sludge has had insignificant effect on the water of Contrary Creek or Lake Anna.

Tributary Stations

Various tributaries of Contrary Creek have been sampled periodically at each mine site for the same AMD parameters as in the regular semi-monthly sampling. At the Arminius Site (Figure 89) Tr-12 and Tr-13 drain the major portion of Arminius East, Tr-14 drains a series of settling ponds where no reclamation has been done, and Tr-15 is an old diversion along the northeast side of the site. At the Boyd Smith Site (Figure 90) Tr-4 is the unaffected portion of the main tributary draining the site. Tr-6 is a very small seep from an old shaft and Tr-7 is just below the confluence of Tr-6 with the main tributary. The entrance of the main tributary into Contrary Creek is known as Tr-8, and two diversions constructed in 1976 are designated Tr-9 and Tr-10, respectively. At Sulphur East (Figure 91) Tr-2 drains from an old shaft entrance, Tr-2A. It is believed that drainage from Tr-2A originates from the large mine pool about 30 meters south of the shaft entrance. At Sulphur West Tr-1 flows from the beaver pond used for irrigation water, and Tr-1A drains a portion of the Tailing Area.

Concentrations and available flows for the tributaries are given in Tables 52-55. It is again apparent that certain metals are characteristic of each site. Note at Tr-12 and Tr-14 of the Arminius Site (Table 52) that despite the high concentrations of sulfates and most metals pH is near normal. At the Boyd Smith Site the pronounced increase in concentrations between Tr-7 and Tr-8 show that most of the AMD from this site seeps from along the main tributary rather than originating from the old shaft at Tr-6 (Table 53). Concentrations were found to be much higher from the Sulphur East tributaries than on the west side (Tables 54 and 55). A comparison of the tributary data with Tables 42-45 indicates that concentrations from the tributaries are generally much higher than in the main stem of Contrary Creek for each respective site.

Besides the regular parameters, a few of the tributary samples were analyzed for some of the other parameters included in the complete analyses and these are presented in Table 56. The high calcium and magnesium values at the Arminius Site suggest the presence of carbonate minerals which may be a factor

TABLE 50. WATER QUALITY DATA - NUTRIENTS AND OXYGEN DEMAND PARAMETERS (mg/1)

Station	Date	Flow (l/s)	P (Tot)	P (Ortho)	N (Tot Kjel)	NH_3 (as N)	$NO_2 + NO_3$ (as N)	NO_2 (as N)	COD	TOC	BOD_5
MS-1	10-27-75	22.9							28	10	2
	5-19-76	30.9							20	12	5
	7- 1-76	4.3	0.1-	0.01-	0.4	0.01-	0.14	0.01-			1-
	5-24-77	5.1	0.1	0.01-	0.2	0.01-	0.1	0.01-	4	7	2
	5-25-78	17.3	0.1-	0.01-	0.1-	0.1-	0.05-	0.01-	24	7	1
	6-12-79	22.7	0.1	0.01	0.3	0.1-	0.05	0.01-	19	14	1
	5-14-80	19.3	0.1-	0.01	0.4	0.1-	0.05-	0.01-	14	9	2
MS-2	10-27-75	34.0							8	10	1
	5-19-76	36.8							32	11	1
	7-1-76	4.0	0.1-	0.01-	0.4	0.1-	0.11	0.01-			1-
	5-24-77	6.2	0.1-	0.01-	0.1-	0.1-	0.1	0.01-	4-	5	1-
	5-25-78	27.5	0.1-	0.01-	0.1-	0.1-	0.1	0.01-	16	3	1
	6-12-79	25.5	0.1-	0.01-	0.3	0.1	0.07	0.01	13	8	1-
	5-14-80	23.5	0.2	0.01	0.4	0.1	0.05-	0.05-	7	11	1
MS-3	10-27-75	59.5							4-	3	1-
	5-19-76	69.4							8	6	1
	7- 1-76	18.7	0.1-	0.01-	0.4	0.2	0.08	0.01-			1-
	5-24-77	18.7	0.1-	0.01-	0.1	0.1-	0.05-	0.01-	4-	3	1-
	5-25-78	50.1	0.1-	0.01-	0.1-	0.1-	0.1	0.01-	16	3	1
	6-12-79	40.5	0.1-	0.01-	0.3	0.1	0.06	0.01-	13	7	1
	5-14-80	45.3	0.1-	0.01-	0.1-	0.1-	0.05-	0.01-	6	6	1
MS-4	10-27-75	84.4							4	4	1
	5-19-76	158.6							8	6	1
	7- 1-76	28.6	0.1-	0.01-	1.0		0.21	0.01-			1-
	5-24-77	28.6	0.1-	0.01-	0.2	0.2	0.05-	0.01-	8	3	1-
	5-25-78	99.4	0.1-	0.01-	0.1	0.1	0.01-	0.01-	16	3	5
	6-12-79	76.5	0.1-	0.01-	0.4		0.07	0.01-	11	3	4
	5-14-80	76.5	0.1-	0.01-	0.2	0.2	0.05-	0.01-	10	6	3
MS-5	10-27-75								16	3	1
	5-19-76	160.9							8	6	1
	7- 1-76	32,3	0.1-	0.01-	0.4		0.05	0.01-			1-
	5-24-77	35.7	0.1-	0.01-	0.1	0.1	0.05-	0.01-	4	4	1-
	5-25-78		0.1-	0.01-	0.2	0.2	0.1	0.01-	20	4	5
	6-12-79	100.0	0.1-	0.01-	0.3		0.05	0.01-	11	4	3
	5-14-80	80.1	0.1-	0.01-	0.1	0.1	0.05-	0.01-	6	4	2

[a] A (-) sign indicates that the concentration was below the indicated level of detection.

TABLE 51. MONTHLY COMPOSITE SLUDGE ANALYSES ON DRY WEIGHT BASIS FROM BLUE PLAINS STP (ppm)

Month/Year	pH	Zn	Ni	Cd	Pb	Hg	Cu	Cr
April 1976	6.6	1710	37.6	16.6	461	4.8	472	455
May 1976	7.1	1805	36.9	17.2	451	5.6	559	587
June 1976	7.5	2020	42.9	17.9	428	2.3	676	668
July 1976	7.1	1535	30.8	11.1	344	2.0	458	476
August 1976	7.3	1770	40.3	15.5	416	3.6	640	744
Sept. 1977	4.3	1825	54.2	18.1	695	5.2	1025	1045
August 1978	5.1	1277	45.4	13.7	510	4.1	768	938
Sept. 1978	5.2	1275	25.5	11.8	390	2.9	750	795
August 1979	4.9	1220	64.0	12.0	600		750	745
Average	6.1	1604	42.0	14.9	477	3.8	678	717
DCLS 1976 analyses	6.5	2529	29.0	17.0	550	5.05	785	659

Source: District of Columbia Environmental Services

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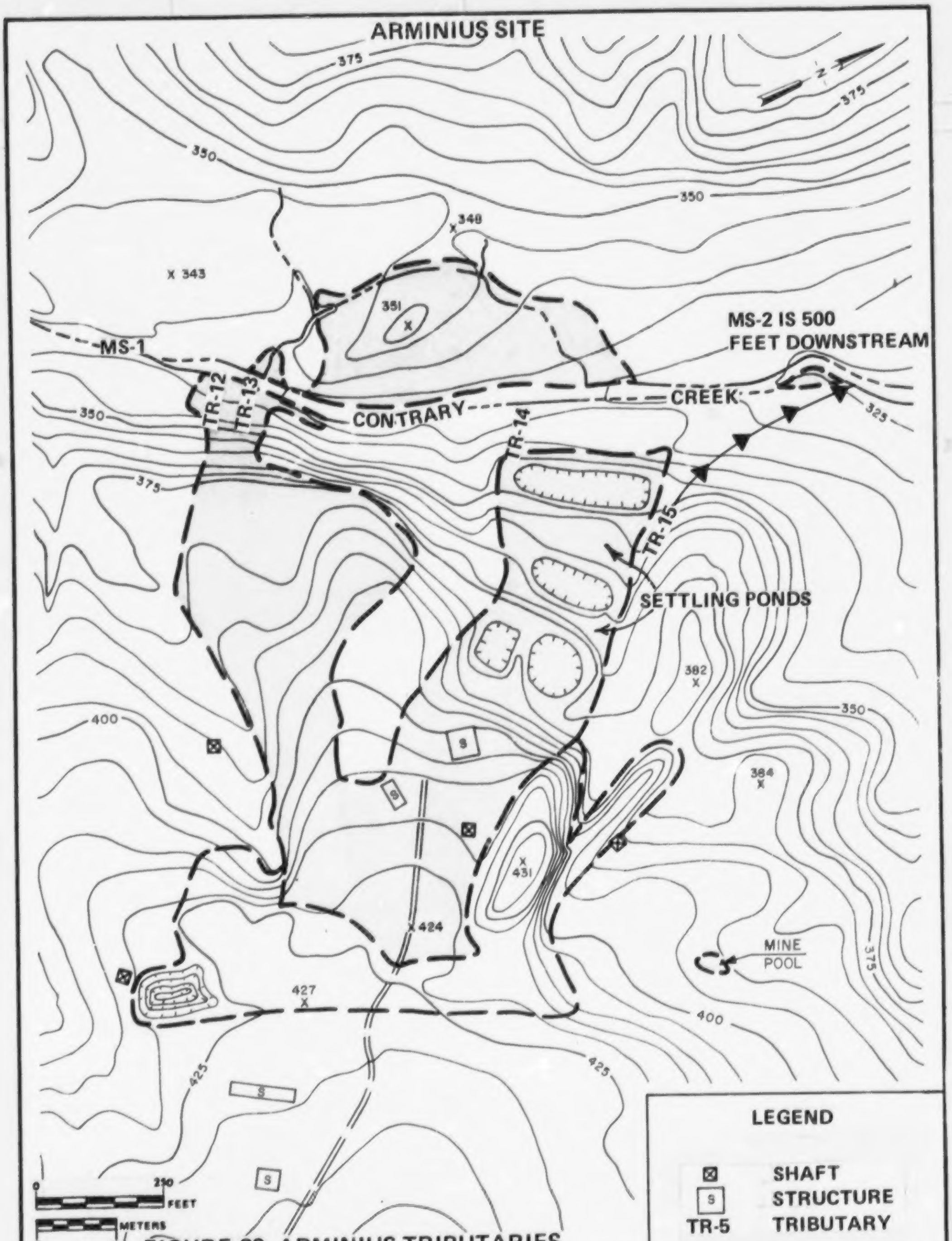

FIGURE 89. ARMINIUS TRIBUTARIES (MODIFIED AFTER MIORIN ET AL, 1974)

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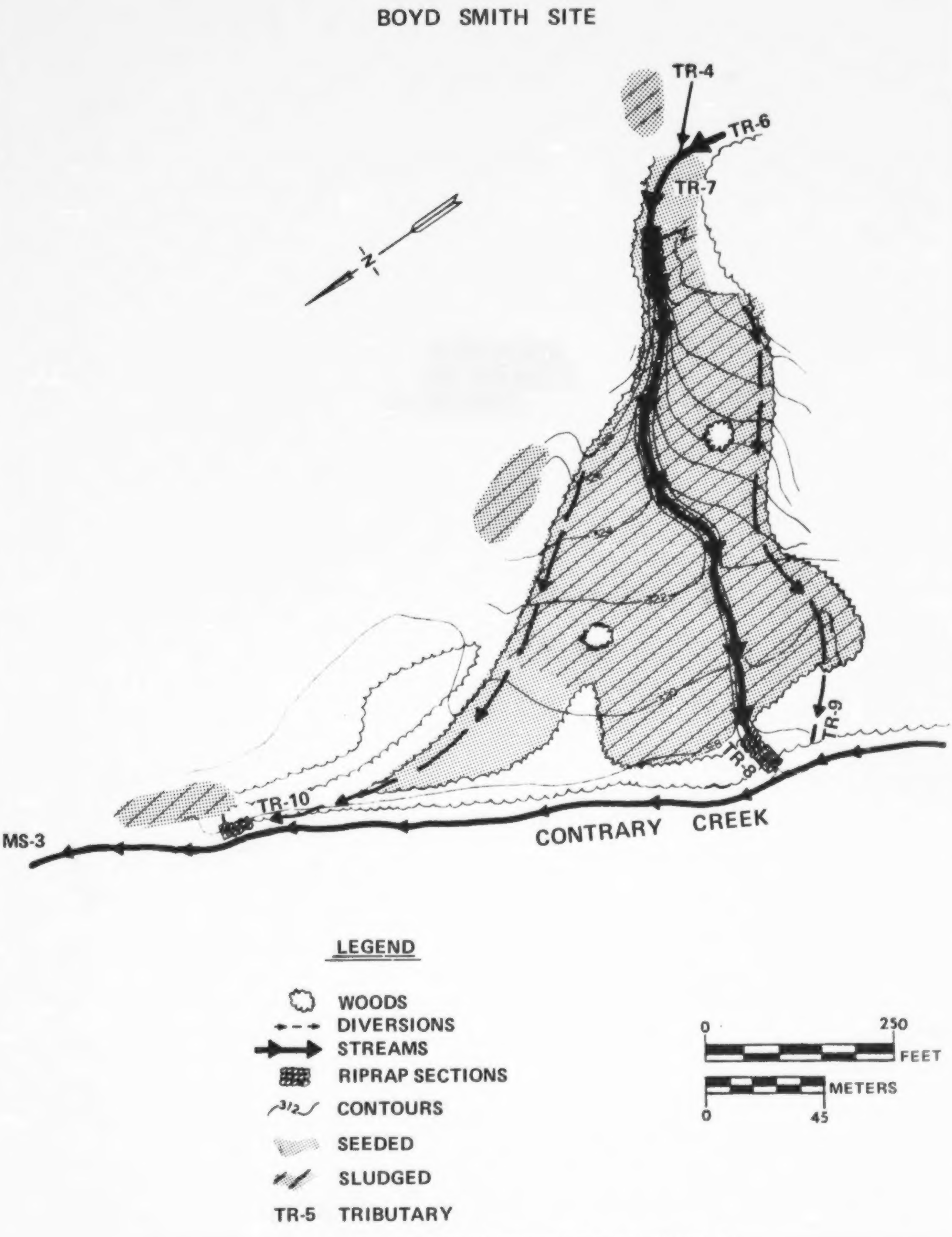

FIGURE 90. BOYD SMITH TRIBUTARIES

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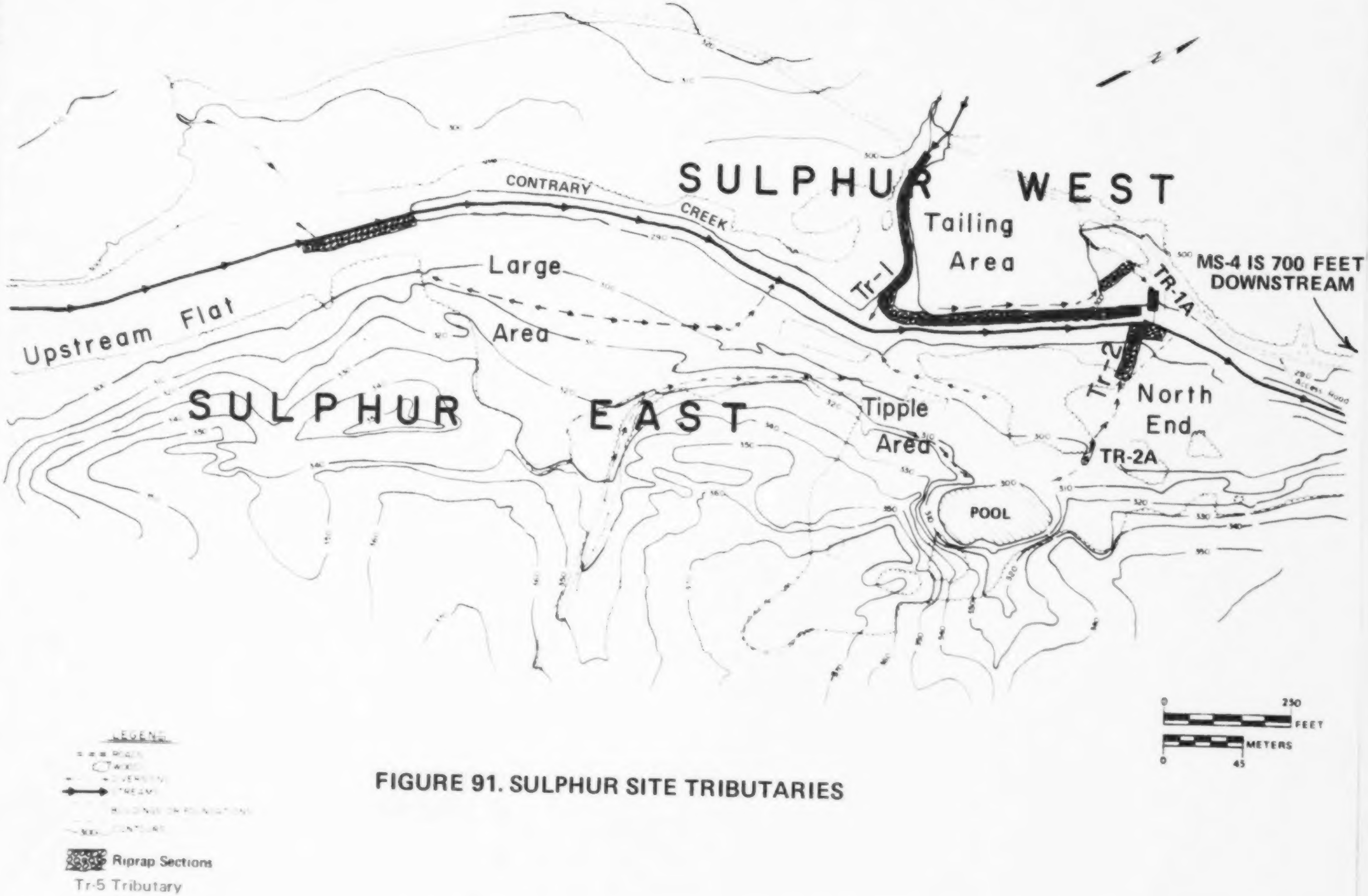

FIGURE 91. SULPHUR SITE TRIBUTARIES

TABLE 52. WATER QUALITY DATA - ARMINIUS TRIBUTARIES (mg/l)[a]

Station	Date	Flow (l/s)	pH	Alkalinity ($CaCO_3$)	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn	Turbidity (NTU)
Tr-12	7-14-76	0.113	7.2		58	2054	0.68	70	0.422	12.0	6.0	225
	8-12-76	0.110	6.4	66	54	2004	0.15	37	0.1-	11.1	14.4	206
	8-25-76	0.102	6.4	63	87	1961	0.20	68	0.1	10.7	14.4	240
	5-24-77	0.130	6.0	32	200	1900	0.01-	63	0.031	12	14.0	38
	8-18-77		6.0	75	225	2300	0.11	78	0.326	12.0	20	390
	7-07-77		6.3	42	120	2150	0.01	77	0.066	11.0	9.6	44
Tr-13	7-14-76	0.014	5.5		267	2855	0.26	100	0.211	16.0	31.0	225
	8-12-76	0.017	4.5		244	2637	0.34	120	0.1-	15.8	24	200
	8-25-76	0.014	4.3	257		2793	0.53	105	0.3	16.7	29	220
Tr-14	6-12-79		6.9	28	101	42	0.70	0.3	0.261	5.6	81	7.2
	10-18-79	0.078	6.5	17	88	1176	0.41	0.2	0.163	3.4	60	7.1
Tr-15	10-18-79	0.120	3.4		1289	3512	9.8	6.0	0.127	2.9	148	0.4

[a] A (-) sign indicates that the concentration was below the indicated level of detection.

TABLE 53. WATER QUALITY DATA - BOYD SMITH TRIBUTARIES (mg/1)

Station	Date	Flow (1/s)	pH	Alkalinity ($CaCO_3$)	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn	Turbidity (NTU)
Tr-4	9-15-74	0.353	6.4	27	15	3	0.01-	3.4	0.010	0.43	0.05	
	4-05-76	2.975	5.9	13	18	9	0.01-	3.0	0.003	0.30	0.53	5.8
Tr-6	9-15-75	0.010	3.0		1245	1040	2.3	40	0.17	11.5	17.0	
	4-05-76	0.031	3.0	1589	0	1895	7.4	13.0	0.064	6.3	32.0	0.4
	6-12-79		3.0		432	72	1.5	19	0.059	1.8	4.9	0.4
Tr-7	9-15-75	0.488	4.1		125	103	0.60	32	0.25	1.16	2.0	
	4-05-76	3.258	4.5	44	0	58	0.25	32.0	0.570	0.52	0.91	64
	6-12-79		4.5		75	77	0.30	9.7	0.074	0.52	11.4	9.5
Tr-8	9-15-75	0.657	3.1		440	728	6.7	230		4.1	18.0	
	4-05-76	3.258	3.4	233	0	394	0.11	1.4	0.013	0.72	1.8	85
	5-19-76	1.263	3.7		266	540	2.1	42	0.293	11.2	9.0	17
	7-14-76	0.442	2.9		420	780	2.7	15.0	0.391	15.0	16.0	1.2
	6-12-79		3.1		302	71	1.7	12.5	0.193	8.1	10.9	2.9
Tr-9	5-19-76	0.119	3.6		254	440	8.0	3.2	0.353	3.6	23.0	17
	7-14-76	0.110	4.9		55	1211	0.09	9.0	0.042	20.0	12.0	40
	6-12-79		3.1		855	41	9.4	1.5	0.311	6.6	42	1.0
Tr-10	5-19-76	0.561	3.9		195	42	1.1	22	0.546	12.5	1.5	74
	7-14-76	0	3.3		450	945	10.0	23.0	0.509	8.4	42.0	27
	6-12-79		3.7		70	25	0.19	0.6	0.096	15	0.96	0.7

[a] A (-) sign indicates that the concentration was below the indicated level of detection.

TABLE 54. WATER QUALITY DATA - SULPHUR EAST TRIBUTARIES (mg/1)

Station	Date	Flow[a] (1/s)	pH	Alkalinity ($CaCO_3$)	Acidity ($CaCO_3$)	SO4	Cu	Fe	Pb	Mn	Zn	Turbidity (NTU)
Tr-2	9-15-75		2.7		961	1640	2.1	72	0.016	11.9	11.3	
	4-05-76		2.8		1000	1630	2.3		0.045	14.0	6.0	0.2
	6-12-79		3.1		1435	268	2.3	138	0.023	14	12.3	5.4
Tr-2A	6-12-79		4.0		1280	228	2.1	162	0.050	14	2.5	2.5
Mine Pool	7-14-76		2.9		825	1106	4.5	35	0.098	10.8	12.7	8
	6-12-79		3.0		539	64	1.9	1.2	0.034	5.9	6.3	1.5

[a] No flow data available.

TABLE 55. WATER QUALITY DATA - SULPHUR WEST TRIBUTARIES (mg/1)

Station	Date	Flow (1/s)	pH	Alkalinity ($CaCO_3$)	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn	Turbidity (NTU)
Tr-1	9-15-75	2.513	5.3	5	20	37.8	0.50	15	0.004	0.40	0.30	
	4-05-76	9.093	4.8	23	2	32.4	0.38	10.0	0.003	0.10	0.43	9.2
	7-14-76	2.635	5.5		12	23.9	0.21	7.0	0.022	0.34	0.33	13
	6-12-79		5.9	4	22	37.	0.23	9.8	0.004	0.43	0.56	36
Tr-1A	6-12-79		4.0		32	69	0.26	2.3	0.027	0.38	0.27	3.7

TABLE 56. WATER QUALITY DATA - MISCELLANEOUS PARAMETERS CONTRARY CREEK TRIBUTARIES (mg/l)[a]

Station	Date	Al	As	Cd	Ca	Cr	Mg	Hg	K	Na	Total Solids	Total Dissolved Solids	Specific Conductance (μmhos/cm)
Arminius Site													
Tr-12	5-24-77	10.0	0.002-	0.02	590	0.01	138	0.0005-	12	9	3577	3473	2700
	8-18-77	0.6	0.012	0.04	550	0.02	156	0.0005-	18	9	3602	3470	2600
Tr-14	6-12-79	2.5	0.001-	0.18	194	0.01-	114	0.0003-	7.4	12	1979	1967	1848
Boyd Smith Site													
Tr-6	6-12-79	35	0.043	0.01-	18	0.02	11	0.0003-	0.8	5	989	989	978
Tr-7	6-12-79	5.6	0.001	0.01-	7	0.02	5	0.0003-	0.7	5	192	181	196
Tr-8	5-19-76	22.2	0.002-	0.01-	54	0.01-	41	0.0005-	2.1	1-	1013	975	860
	6-12-79	30	0.030	0.04	45	0.03	35	0.0003-	2.8	6	1104	1099	1141
Tr-9	5-19-76	22.8	0.002	0.01-	29	0.01-	37	0.0006	1.1	1-	902	848	760
	6-12-79	83	0.115	0.29	48	0.05	69	0.0003-	4.9	4	1894	1894	1848
Tr-10	5-19-76	11.9	0.002-	0.01-	139	0.01-	98	0.0005-	7.5	4	1696	1406	1300
	6-12-79	3.2	0.001-	0.02	157	0.01-	113	0.0003-	4.7	12	1776	1776	1576
Sulphur Site													
Tr-1	6-12-79	1.6	0.003	0.01-	9	0.01-	3	0.0003-	1.2	4	160	142	132
Tr-1A	6-12-79	1.6	0.001-	0.01-	9	0.01-	3	0.0003-	2.0	13	168	164	196
Tr-2	6-12-79	102	0.132	0.04	98	0.01-	103	0.0003-	6.6	6	3486	3479	2366
Tr-2A	6-12-79	98	0.125	0.04	91	0.03	105	0.0003-	7.9	6	3504	3494	2527
Mine Pool	6-12-79	63	0.095	0.03	43	0.03	46	0.0003-	4.5	4	1395	1394	1517

[a] A (-) sign indicates that the concentration was below the indicated level of detection.

contributing to the lower acidity at this site than would be expected.

pH and Specific Conductance Transects - 1979

In the summer of 1979 a pH and specific conductance transect was run for 6.6 kilometers at 100-meter intervals along the entire length of Contrary Creek from Lake Anna to above the Arminius Site. Tables 57 and 58 and Figure 92 present the results of this transect which includes the only water quality data available for the stream reaches between the mine sites and the downstream reach of Contrary Creek to Lake Anna. The increasing conductivity and declining pH in the downstream direction again showed how water quality is degraded as it passes each mine site. The abrupt drop in pH at the Boyd Smith Site occurs where Tr-8 enters the main channel, but the magnitude of the drop is difficult to explain considering the prevailing pH's recorded below the Boyd Smith Site over the course of the monitoring program. Note that the pH made a slight recovery between the Boyd Smith and Sulphur Site but there was a dramatic drop from 4.5 to 2.9 as the stream passed through the Sulphur Site, and there was a continued decrease downstream to Lake Anna. The specific conductance predictably increased downstream with sharp rises at the Arminius and Sulphur Sites. The sudden decrease in conductivity and slight improvement in pH between the Arminius and Boyd Smith Sites may be due to a fresh water tributary entering Contrary Creek in that vicinity. The conductivity curve also reflects an improvement between the Boyd Smith and Sulphur Sites, but it is obvious that metal concentrations steadily increase between the Sulphur Site and Lake Anna.

A close-interval transect for conductance only was run at the Boyd Smith Site to compare conditions along each side of the stream and at mid-stream. A pronounced increase in conductance below the confluence of Tr-8 was noted on the southeast side of the stream adjacent to the mine site. Results of this transect are shown in Table 59 and Figure 93. A pH and conductance transect was also run along Tr-8 at the Boyd Smith Site (Table 60 and Figure 94). This transect revealed that most of the AMD seeping into this tributary is along an 80-meter stretch in the uppermost affected reach. Refer to Table 53 for analytical data from Tr-8.

A pH and conductance transect through the entire length of the Sulphur Site appears in the special study by UVA in Appendix D.

Lake Stations

Two stations in the Contrary Creek arm of Lake Anna were sampled concurrently with the stream stations from October 1975 until early 1980 and were analyzed for the same parameters. There were significant gaps in the lake data during the winters of 1976-77 and 1977-78 when ice and inclement weather prohibited sampling. The stations are designated SS-1 and SS-2 and are shown on Figure 56. SS-1 is 1.7 kilometers from the mouth of Contrary Creek where depth is about 3 meters. SS-2 is at the juncture of the Contrary Creek arm with the main body of Lake Anna approximately 5 kilometers from MS-5. Depth at SS-2 is about 9 meters. Samples were collected at surface, middle, and bottom depths at each station as indicated below.

TABLE 57. pH AND SPECIFIC CONDUCTANCE DATA FOR 6.6 KM TRANSECT ALONG CONTRARY CREEK, JULY 30, 1979

Meters upstream from Creek mouth at Lake Anna	pH	Specific Conductance (μmhos/cm)	Remarks
0	2.6	1200	Began at tree stump on lake shore.
100	2.6	1180	
200	2.6	1150	
300	2.7	1130	
400	2.7	1140	
500	2.7	1140	
600	2.7	1100	
700	2.7	1080	
800	2.7	1090	Fresh tributary enters from south @ 825 m.
900	2.7	1100	Broad floodplain from 900 m to 1200 m with laminated beds of pyrite and quartz sand.
1000	2.7	1040	
1100	2.7	1020	Fresh tributary enters from north @ 1190 m.
1200	2.7	1050	
1300	2.8	1010	
1400	2.8	974	Broad floodplain from 1400 to 1700 m with laminated beds of pyrite and quartz sand.
1500	2.8	944	
1600	2.8	917	
1700	2.9	907	
1800	2.9	887	
1900	2.9	865	Pyrite sand and iron hydroxide precipitate seen in creekbed all the way to lake.
2000	2.9	887	
2100	2.9	925	MS-4, gaging station at 2100 m.
2200	3.0	909	Fresh tributary enters from west @ 2198 m, downstream limit of major Sulphur Site tailings at 2175 m.
2300	3.1	870	
2400	3.2	773	
2500	3.4	695	
2600	3.7	610	Fresh tributary (Tr-1) enters from west at 2635 m.
2700	3.9	438	
2800	3.9	438	
2900	4.5	372	Upstream limit of major Sulphur Site tailings at 2900 m.

(continued)

TABLE 57. (continued)

Meters upstream from Creek mouth at Lake Anna	pH	Specific Conductance (µmhos/cm)	Remarks
3000	4.6	375	Fresh tributary enters from west @ 3025 m.
3100	4.5	389	
3200	4.6	387	
3300	4.7	386	
3400	4.8	387	
3500	4.8	389	
3600	4.8	415	
3700	4.6	433	Tributary enters from east @ 3730 m, draining a swamp.
3800	4.5	441	
3900	4.5	437	
4000	4.4	461	
4100	4.4	459	
4200	4.5	463	
4300	4.5	450	
4400	4.6	452	MS-3, gaging station at 4475 m.
4500	4.7	428	Fresh tributary enters from west and mine seepage enters from east (Tr-10) at 4522 m, marking the downstream limit of Boyd Smith Site tailings.
4600	4.4	496	
4700	4.5	496	Fresh tributary enters from west and mine drainage enters from east (Tr-8) at 4702 m, marking the upstream limit of Boyd Smith Site tailings.
4800	6.2	470	
4900	6.3	471	
5000	6.4	470	
5100	6.4	465	
5200	6.5	457	
5300	6.4	233	
5400	6.5	231	Large rock outcrop and rapids @ 5400 m, fresh tributary enters from west at 5430 m.
5500	6.1	343	
5600	6.1	354	MS-2 gaging station at 5613 m.
5700	6.2	352	
5800	6.2	346	Downstream limit of Arminius Site tailings @ 5850 m.
5900	6.3	338	
6000	6.3	292	Mine seepage trickles from Arminius West tailings.

(continued)

TABLE 57. (continued)

Meters upstream from Creek mouth at Lake Anna	pH	Specific Conductance (μmhos/cm)	Remarks
6100	6.9	193	Small mine tributaries enter from east at 6198 and 6175 m (Tr-12 and Tr-13) respectively.
6200	7.1	69.1	Upstream limit of Arminius Site tailings @ 6225 m.
6300	7.2	63.3	MS-1, gaging station @ 6257 m, fresh tributary enters from west at 6245 m.
6400	7.1	62.8	
6500	7.0	62.2	
6600	6.9	62.2	End of transect, very low flow near headwaters.

Source: Dagenhart (1980).

TABLE 58. pH AND SPECIFIC CONDUCTANCE DATA OF CONTRARY CREEK TRIBUTARIES, JULY 30, 1979

Meters from Contrary Creek mouth to confluence w/trib.	pH	Specific Conductance (µmhos/cm)	Remarks
825			Very low flow from south, sample lost, clean looking.
1190	6.5	48.5	Low flow from north, clean looking.
2198	6.6	33.7	Medium flow from west, clean looking.
2635	6.5	101	Medium flow from west, known as Tr-1, flows through 100 m of tailings from beaver pond.
3025	7.1	29.7	Medium flow from west from a pond, clean looking.
3730	6.6	118	Very low flow from east, draining a swamp, dirty irridescent water.
4522	7.1	38.3	Medium flow from west, clean looking.
4522	3.4	1891	Extremely low flow from east, polluted tributary (Tr-10) from Boyd Smith Site.
4702	7.0	31.6	Very low flow from west, clean looking.
4702	2.9	1424	Low flow from east, polluted tributary (Tr-8) from Boyd Smith Site.
5430	7.2	30.6	Medium flow from west, clean looking.
6175	6.6	3181	Very low flow from east, polluted tributary (Tr-13) from Arminius Site.
6198	6.5	3757	Very low flow from east, polluted tributary (Tr-12) from Arminius Site
6245	7.0	37.1	Medium flow from west, clean looking.

Source: Dagenhart (1980).

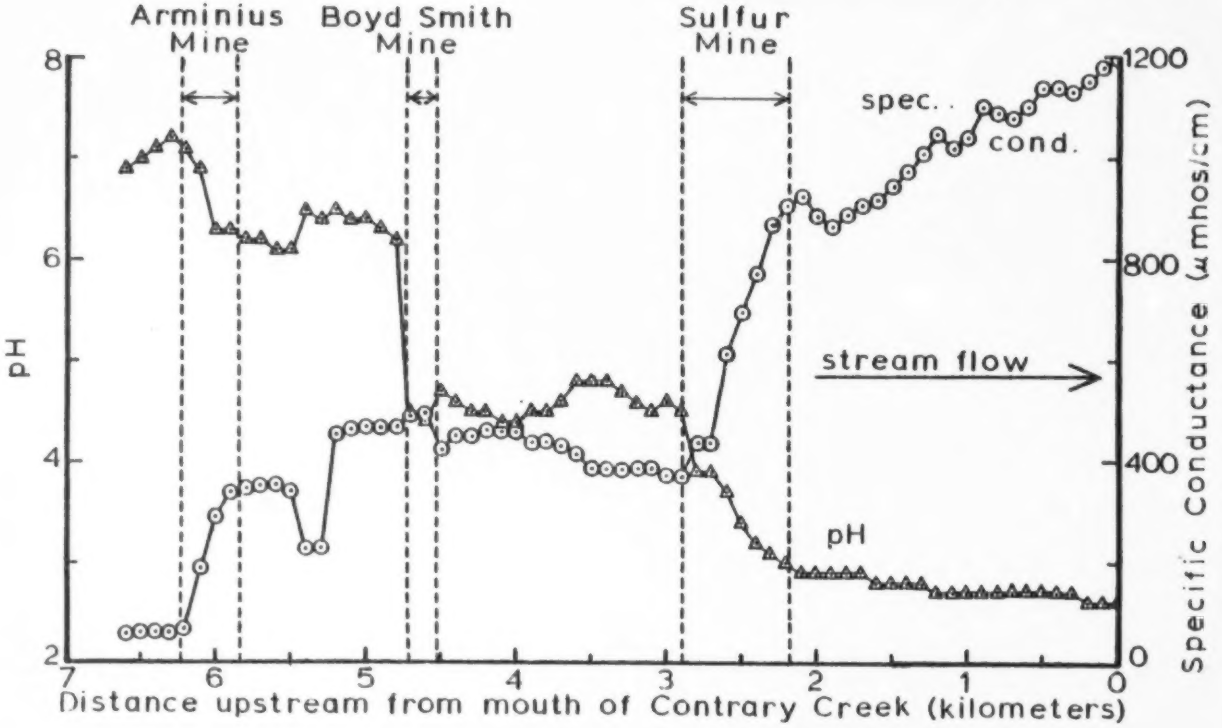

Figure 92. pH And Specific Conductance Transect From Lake Anna to Above Arminius Site, July 30, 1979 (Source: Dagenhart, 1980).

TABLE 59. SPECIFIC CONDUCTANCE DATA FOR TRANSECT ALONG CONTRARY CREEK AT BOYD SMITH MINE SITE, JULY 19, 1979

Meters Upstream from MS-3	Specific Conductance (μmhos/cm) North-west side	Mid-stream	South-east side	Remarks
0	312	315	322	At gaging station, MS-3, beginning of Boyd Smith Site.
25	207	298	339	Tr-10 trickles from east @ 49 m, fresh tributary with moderate flow from west @ 49 m.
50	327	328	335	
75	332	329	331	
100	327	330	343	
125	327	328	333	
140	328	329	336	Tree down in creek and ponding water at 150 m interval.
175	323	329	328	
200	322	350	350	
225	193	321	410	Tr-8 enters from east with low flow at 240 m, fresh tributary with low flow enters from west at 228 m.
250	311	318	316	Upstream from all Boyd Smith Site tailings.
275	313	321	321	
300	319	320	321	
350	317	321	317	

Source: Dagenhart (1980).

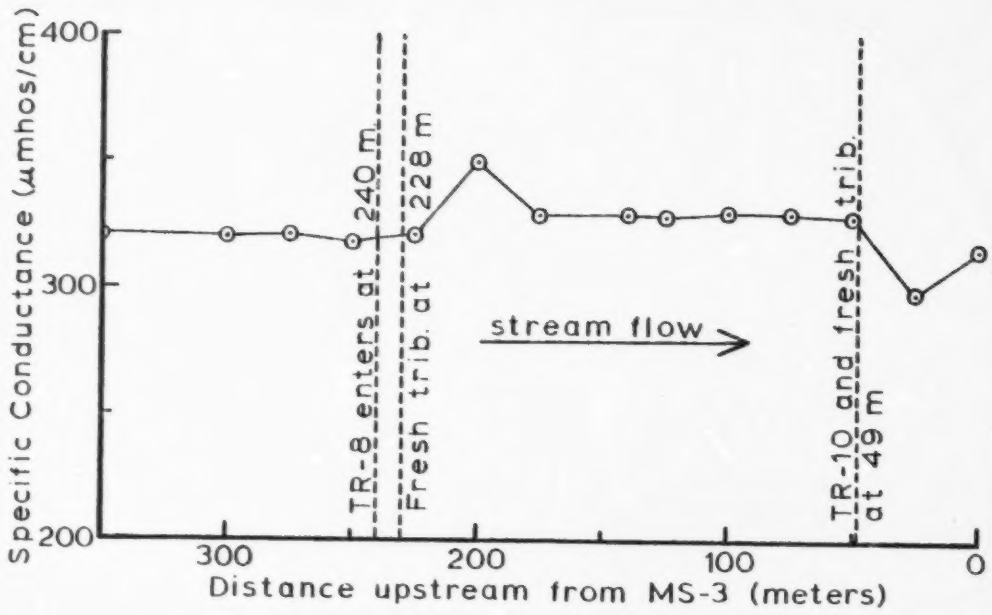

Figure 93. Specific Conductance Transect Along Contrary Creek At Boyd Smith Site, July 19, 1979 (Source: Dagenhart, 1980).

TABLE 60. pH AND SPECIFIC CONDUCTANCE DATA FOR TRANSECT ALONG MAIN TRIBUTARY (Tr-8) FROM BOYD SMITH SITE, JUNE 19, 1979

Meters Upstream from Tr-8 confluence with Contrary Creek	pH	Specific Conductance (μmhos/cm)	Remarks
0	3.08	1160	First 10 m of tributary lined with granite riprap.
5	3.10	1160	
10	3.09	1160	
15	3.10	1170	
20	3.15	1170	From 20 m to 180 m, a greenish blue-gray clayey sub-soil is visible along much of Tr-8's bank and bed.
25	3.11	1160	
30	3.13	1150	
35	3.10	1160	
40	3.10	1160	Wooden gaging post at 43 m, station known as Tr-8.
45	3.10	1150	
50	3.09	1160	
55	3.02	1160	
60	3.05	1160	
65	3.04	1150	
70	3.05	1140	
75	3.04	1140	
80	3.00	1180	
85	3.00	1180	
90	3.00	1160	
95	3.01	1160	
100	3.01	1160	
105	3.05	1170	
110	3.06	1170	
115	3.07	1150	
120	3.09	1160	
125	3.09	1140	
130	3.10	1160	
135	3.08	1170	
140	3.11	1150	
145	3.06	1190	
150	3.10	1170	
155	3.15	1140	
160	3.15	1140	
165	3.15	1160	
170	3.17	1150	
175	3.19	1140	
180	3.18	1140	

(continued)

TABLE 60. (continued)

Meters Upstream from Tr-8 confluence with Contrary Creek	pH	Specific Conductance (umhos/cm)	Remarks
185	3.19	1130	
190	3.23	1130	
195	3.25	1110	Visible acid seepage along banks from 195 to 215 m.
200	3.26	1090	
205	3.25	1040	
210	3.28	964	
215	3.30	904	Granite riprap lining banks begins at 218 m.
220	3.30	898	
225	3.31	875	
230	3.33	831	
235	3.35	801	
240	3.35	773	Granite riprap lining banks ends at 242 m.
245	3.40	715	
250	3.40	708	
255	3.48	641	
260	3.50	624	
265	3.51	612	
270	3.54	621	
275	3.64	519	
280	3.65	510	
283	3.71	457	
286	3.83	359	
290	3.87	332	
295	4.15	245	V-notch weir at 298 m, known as Tr-7.
300	4.50	177	
305	4.01	308	Tributary is poorly mixed here; Tr-6, a polluted tributary enters at 308 m.
315	6.20	65	Background level of the tributary before entering mine tailings, sample taken above V-notch weir known as Tr-4.

Source: Dagenhart (1980).

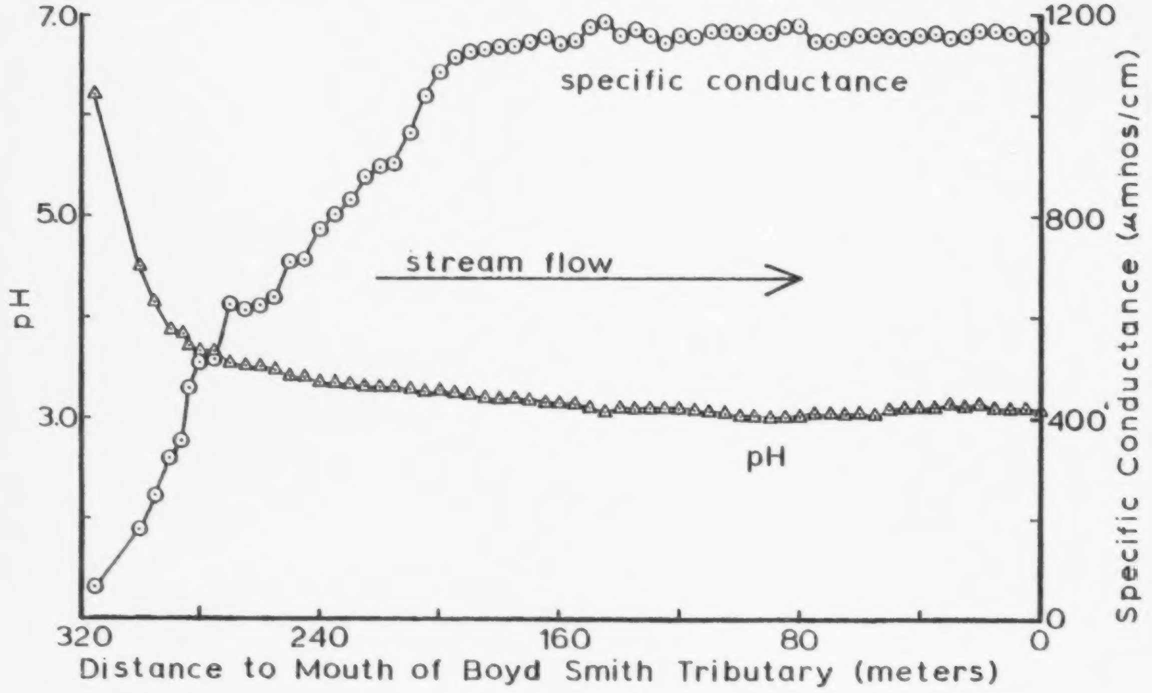

Figure 94. pH And Specific Conductance Transect Along Tr-8 At Boyd Smith Site, June 19,1979 (Source: Dagenhart, 1980).

SS-1

Surface - 0.3 m (1 ft)
Middle - 1.5 m (5 ft)
Bottom - 3.0 m (10 ft)

SS-2

Surface - 1.2 m (4 ft)
Middle - 4.6 m (15 ft)
Bottom - 9.1 m (30 ft)

Since much of the lake data is highly erratic and difficult to explain, a detailed interpretation has not been attempted, and all of the factors affecting the lake chemistry is beyond the scope of this report. Summaries of the data comparing conditions at SS-1 and SS-2 are presented along with several concentration curves that reflect seasonal variation. It should be kept in mind that the Contrary Creek arm of Lake Anna covers the former stream bed which was laden with mine wastes all the way out to the present site of SS-2 (see sediment data in the biologic survey included in Appendix D).

Table 61 shows average, minimum, and maximum values of pH and concentrations recorded at SS-1 from October 1975 to October 1979. Figures 95-102 are plots of individual pH and concentrations determined from the semi-monthly sampling at the surface and bottom levels of SS-1. The data gaps during the winters of 1976-77 and 1977-78 tend to present somewhat misleading trends in the plots for the cold weather season. The influence of seasonal stratification in the shallow part (3 m) of the lake at SS-1 is probably slight, but there was a tendency for all concentrations to be higher at the bottom level during the summer months which apparently resulted from lower dissolved oxygen. However, it appears that the influx rate of AMD loads from Contrary Creek exerts much more influence at SS-1 than effects of stratification. A study of the stream hydrographs did not show any significant effects of any one storm increasing the concentrations at SS-1, but it must be realized that the sampling represents only chance conditions and no deliberate effort was made to collect lake samples to determine effects of storms. The quality data does reflect uniform conditions at all three levels after a few storms indicating a mixing of the water column.

Zinc concentration reached the SWCB limit of 5.0 mg/l only once at SS-1 (bottom level), and copper exceeded the limit of 1.0 mg/l only a few times over the monitoring period. The extremely low concentrations of copper and zinc during the summer of 1977 apparently resulted from negligible metal loads being carried into Lake Anna by the meager flows during the prolonged drought, but sharp increases in zinc and copper concentrations occurred at each depth when rains came in the fall and began flushing out metals that had built up to high concentrations upstream during the hot dry weather (Figures 97-100). A similar pattern, though more subdued, can be seen associated with the less severe drought of 1976. The pH curves also seem to reflect this pattern with values in the 6 to 7 range in the summer months when flows were low and then falling to the 3 to 5 range when higher flows were entering from Contrary Creek. This pattern is well pronounced at the surface and middle levels, but the curve for the bottom level (Figure 96) is more erratic where stratification is probably a factor.

On the other hand, iron concentrations tended to be much higher at the bottom level during the hot summer months of 1977 when dissolved oxygen was

TABLE 61. SS-1 - AVERAGES, MINIMUMS, AND MAXIMUMS OF WATER QUALITY DATA, 1975-79 (mg/l) [a]

Depth (m)	Avg.	Min.	Max.
	pH		
0.3	5.1	3.8	7.5
1.5	5.3	3.9	8.5
3.0	5.0	3.3	7.8
	Acidity (CaCO)		
0.3	20	1	138
1.5	16	2	146
3.0	24	1	160
	SO_4		
0.3	34	10	129
1.5	30	9	52
3.0	42	8	205
	Cu		
0.3	0.11	0.01-	0.39
1.5	0.12	0.01-	1.00
3.0	0.27	0.01-	2.60
	Fe		
0.3	1.3	0.1-	8.0
1.5	1.1	0.1	5.8
3.0	3.1	0.3	40.0
	Mn		
0.3	0.33	0.01	1.03
1.5	0.32	0.05	0.92
3.0	0.57	0.07	14.0
	Zn		
0.3	0.49	0.01-	1.90
1.5	0.47	0.01	0.97
3.0	0.73	0.02	5.00

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[a] A (-) sign indicates that the concentration was below the indicated level of detection.

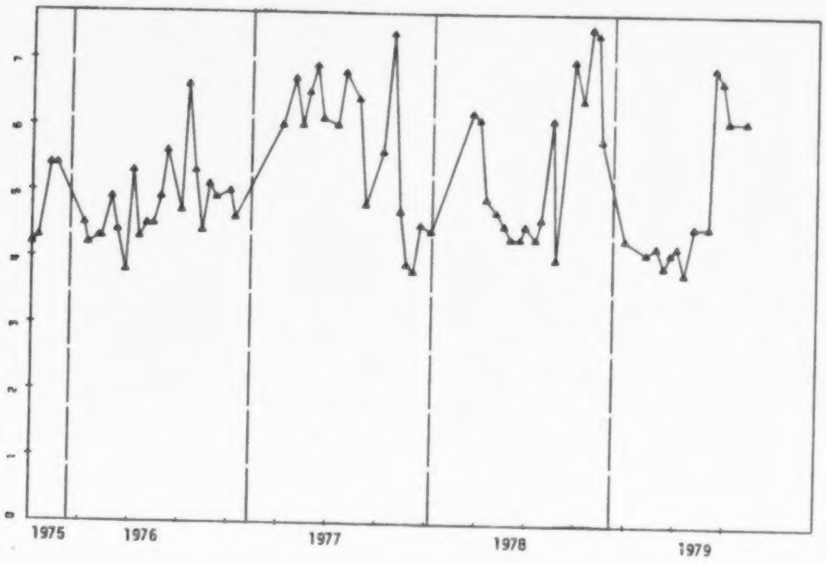

Figure 95. pH versus time in calendar years at surface level of SS-1.

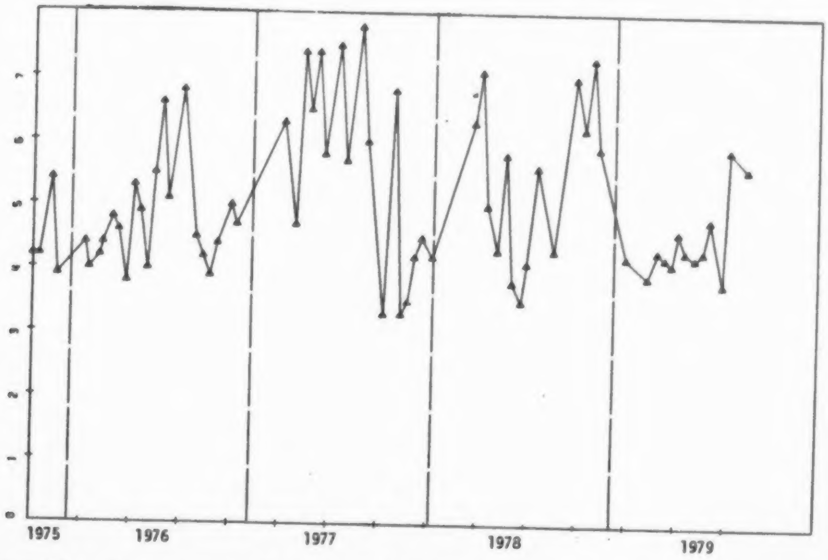

Figure 96. pH versus time in calendar years at bottom level of SS-1.

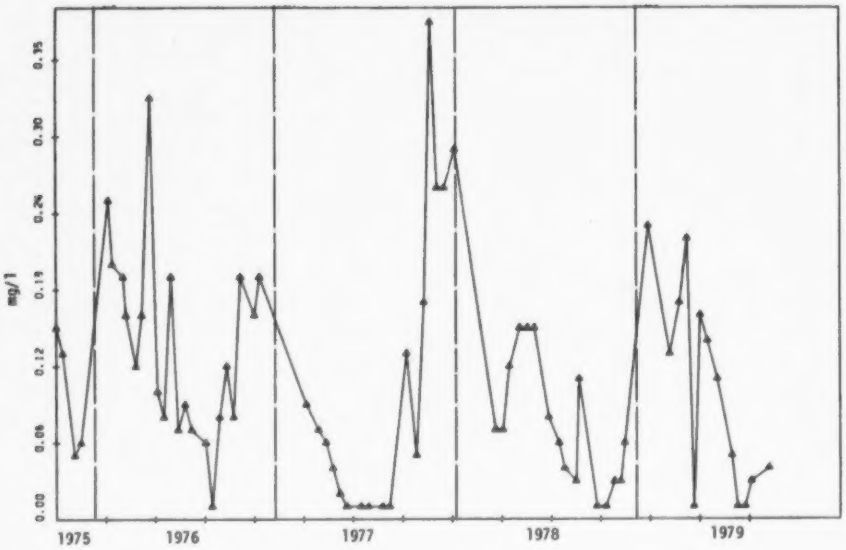

Figure 97. Copper concentrations versus time in calendar years at surface level of SS-1.

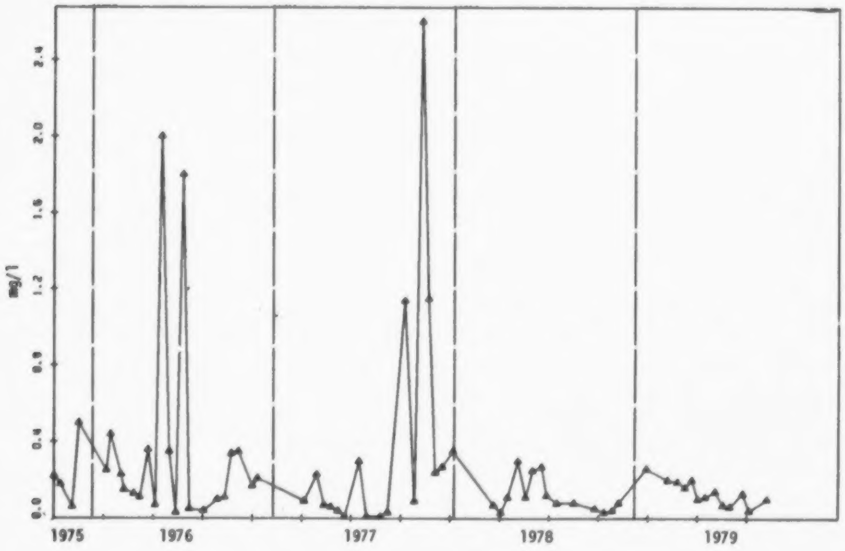

Figure 98. Copper concentrations versus time in calendar years at bottom level of SS-1.

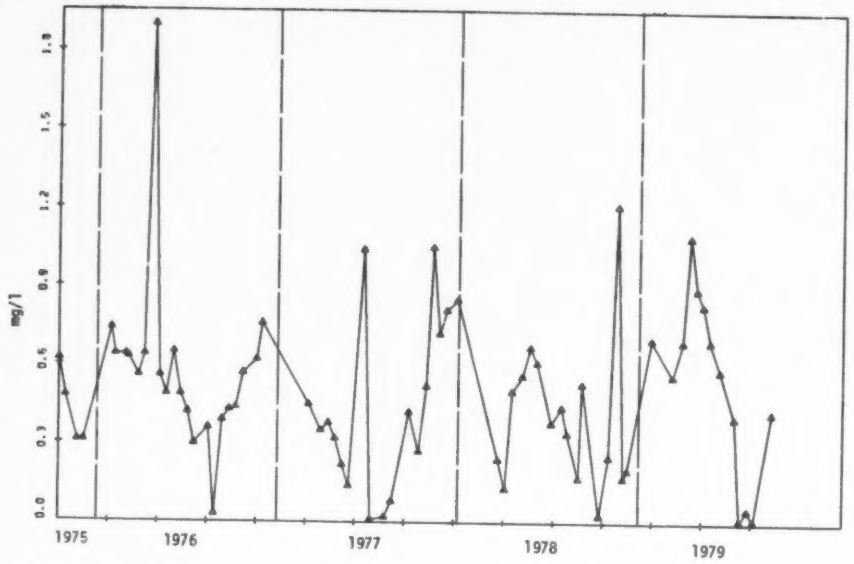

Figure 99. Zinc concentrations versus time in calendar years at surface level of SS-1.

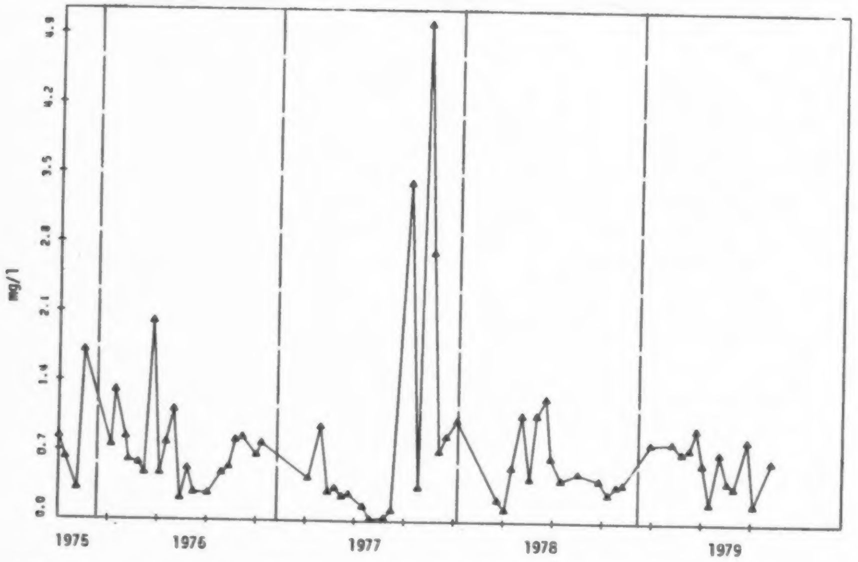

Figure 100. Zinc concentrations versus time in calendar years at bottom level of SS-1.

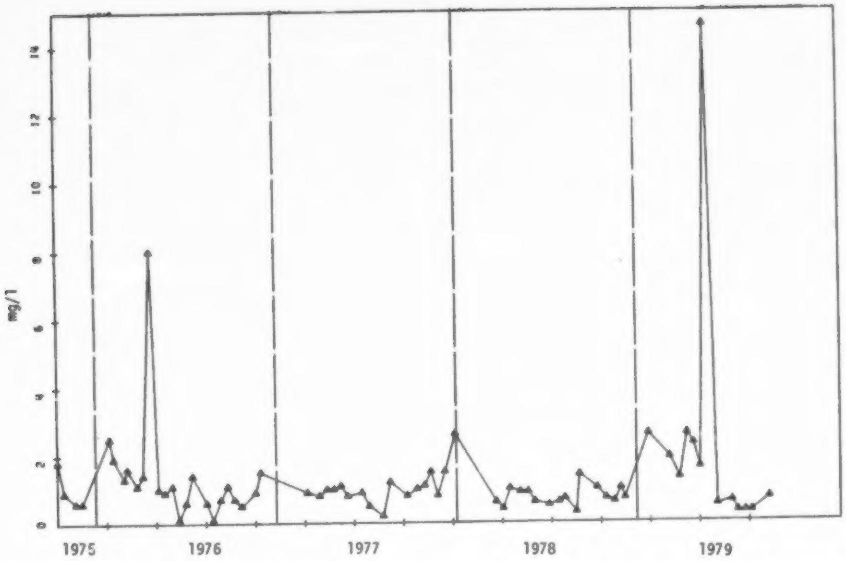

Figure 101. Iron concentrations versus time in calendar years at surface level of SS-1.

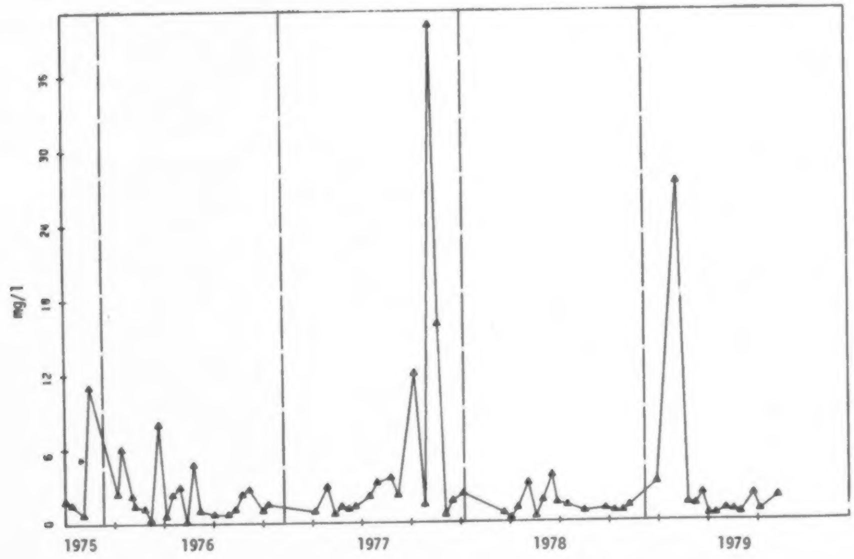

Figure 102. Iron concentrations versus time in calendar years at bottom level of SS-1.

very low suggesting the influence of summer stratification. Manganese showed the same trend but to a lesser degree. There appeared to be a similar trend of higher concentrations of iron and manganese at the bottom levels during the summers of the other years, but none are as pronounced as in 1977. Both iron and manganese concentrations consistently exceeded SWCB standards at SS-1. Sulfate and lead concentrations tended to be even more erratic than the other parameters but they still showed the influence of the flushing out after the buildup of concentrations during the summer of 1977. Lead concentrations occasionally exceeded the SWCB limit of 0.05 mg/l at all levels. The reason for the abrupt rise in concentrations with lowering of pH in the spring of 1976 is not clear. This spike could be associated with the warmer temperatures during the spring turnover or it possibly may have resulted from the initial disturbance of the mine wastes upstream when the reclamation work began. However, the latter possibility is considered remote, because a similar pattern and much more pronounced was observed at SS-2 on the same date.

The concentration data collected at SS-2 indicated that AMD from Contrary Creek may still be of some slight influence in this part of the lake, but there does not appear to be nearly as much of a direct relationship to the influx of loads as at SS-1. The effect of seasonal stratification is undoubtedly much more of a factor at SS-2 than at SS-1. A comparison of Table 61 with Table 62 gives an indication of the relative concentrations at the two stations. Concentrations were generally more erratic at the bottom level (9 m) and exhibited some abrupt increases which probably resulted from oxygen depletion during the summer months. The pH was the lowest in early spring ranging from 4.5 to 5.0 and tended to reach alkaline values exceeding 7 in the summer. Copper and zinc concentrations reflected the same trend being lowest in the summer with a gradual rise in the fall and then sharp increases in late winter. Iron (Figures 103-104) and manganese concentrations showed a very consistent seasonal pattern with quite uniform conditions at each level during fall and winter and then a well-defined summer stratification with concentrations increasing downward. As at SS-1 the sulfate and lead values tended to be more irregular with less defined patterns. There were several abrupt increases in various concentrations, the cause of which is not entirely clear, but some were likely due to seasonal turnover and stratification.

Further comparisons of conditions at SS-1 and SS-2 are shown by averaging the data from all three depths in Table 63 and by the solids and conductivity data in Table 64 for five sample dates when the annual complete analyses were run. The complete analyses also included tests for arsenic, cadmium, chromium, and mercury. None of these metals were found above the limit of detection at the lake stations except for arsenic on one occasion, and it was within SWCB water quality standards. From all of the lake data analyzed it appears that normal seasonal concentrations remained near the same levels.

TABLE 62. SS-2 - AVERAGES, MINIMUMS, AND MAXIMUMS OF WATER QUALITY DATA - 1975-79 (mg/l).[a]

Depth (m)	Avg.	Min.	Max.
	pH		
1.2	6.7	4.2	8.3
4.6	6.6	4.4	8.4
9.1	6.5	3.7	8.2
	Acidity ($CaCO_3$)		
1.2	11	1	72
4.6	12	1	70
9.1	15	1	67
	SO_4		
1.2	14	2	43
4.6	13	4	42
9.1	14	4	76
	Fe		
1.2	0.4	0.1-	3.1
4.6	0.5	0.1-	7.0
9.1	1.2	0.1-	12.6
	Mn		
1.2	0.16	0.01	0.53
4.6	0.22	0.01-	3.30
9.1	0.41	0.01-	3.30
	Zn		
1.2	0.13	0.01-	1.0
4.6	0.13	0.01-	0.96
9.1	0.18	0.01-	1.05

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[a] A (-) sign indicates that the concentration was below the indicated level of detection.

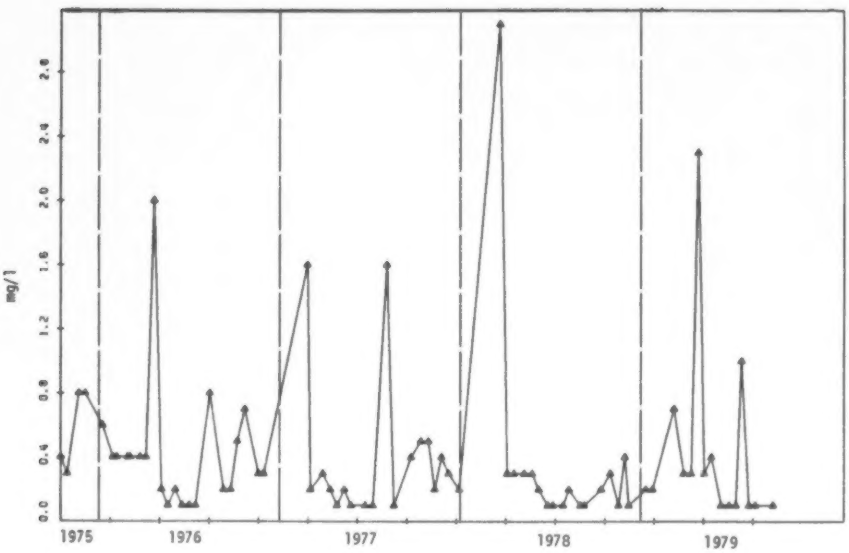

Figure 103. Iron concentrations versus time in calendar years at surface level of SS-2.

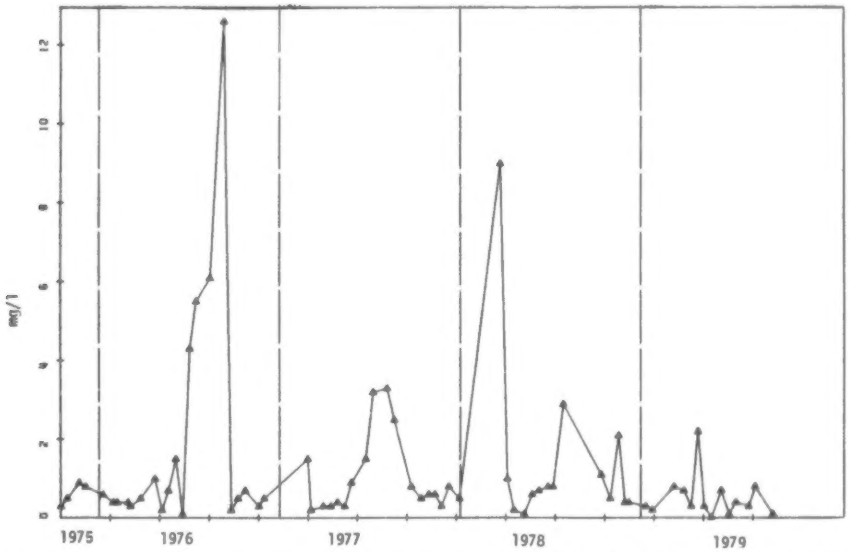

Figure 104. Iron concentrations versus time in calendar years at bottom level of SS-2.

TABLE 63. COMPARISON OF AVERAGES OF ALL DEPTHS AT SS-1 AND SS-2 - 1975-79 (mg/l)

Station	pH	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Mn	Zn
SS-1	5.1	20	35	0.17	1.8	0.41	0.56
SS-2	6.6	13	14	0.03	0.3	0.26	0.15

TABLE 64. COMPARISON OF SOLIDS AND SPECIFIC CONDUCTANCE AT SS-1 AND SS-2

Date	Depth[a]	Total Solids (mg/l)		Total Solids (mg/l)		Specific Conductance (μmhos/cm)	
		SS-1	SS-2	SS-1	SS-2	SS-1	SS-2
10-27-75	S	102	70	96	62	110	54
	M	103	78	97	74	110	57
	B	120	81	116	73	130	62
5-19-76	S	299	124	251	122	250	104
	M	98	96	76	76	88	56
	B	108	101	84	91	84	54
5-24-77	S	165	83	161	81	75	56
	M	74	73	69	69	90	55
	B	106	84	100	81	75	65
5-25-78	S	77	45	75	41	103	58
	M	71	49	68	45	93	60
	B	56	53	49	47	73	67
6-12-79	S	73	41	72	39	94	52
	M	64	42	63	40	89	52
	B	83	50	81	47	150	56

[a] S-surface M-middle B-bottom See Page 160 for depths.

Summary of Water Quality Data

A general overview of the monitoring data indicates that there has been little improvement in the water quality in the project area since reclamation began. Concentrations and loads tend to be near the same seasonal levels as before reclamation and the same general problem areas continue to persist. Tables 65 and 66 and Figures 105-108 show a comparison of concentrations and loads by water years. The Sulphur Site is obviously still the major source of AMD with the Boyd Smith Site presenting the least problem and the Arminius Site of intermediate consequence. This project has included no abatement measures on the downstream reach of Contrary Creek between the Sulphur Site and Lake Anna, and no reclamation work is contemplated on this reach of the stream.

It must be realized that the droughts of 1976 and 1977 which were each followed by abnormally cold winters came at a most critical time and seriously hampered efforts to establish vegetation on the formerly denuded areas. This undoubtedly delayed any chance of realizing any significant reduction of AMD entering Contrary Creek. In fact, considering the devastated conditions that existed before reclamation, it was probably unrealistic to expect any improvement within such a short period even with normal seasons. More abundant rainfall in 1978 and 1979 coupled with milder falls and winters greatly improved vegetative growth on the reclaimed sites but minimal gains were realized in 1980 due to another dry summer.

Figure 109 illustrates the sources of AMD to Contrary Creek. The major contribution during dry periods was the leaching of the mine waste by water percolating through the waste and the leaching of the waste deposited in the stream bed. A smaller source was AMD flowing from underground workings. During precipitation events, runoff carried AMD and mine waste from the waste piles.

The reclamation of the mining waste was expected to reduce the AMD load in Contrary Creek in several ways:

1. Removal of toxic mining waste from the stream bed at the Sulphur Site would remove this source of AMD.

2. Grading to facilitate rapid runoff and minimize infiltration would reduce the volume of water leaching the mine waste.

3. Development of a vegetative stabilized cover over the toxic mine waste would:

   a. Eliminate the erosion and transport of mine waste into the stream.

   b. Reduce the water available for leaching of the mine waste as a result of plant transpiration.

   c. Reduce oxygen contact with the pyrite in the mine waste and

TABLE 65. AVERAGE ANNUAL CONCENTRATIONS BY WATER YEAR AT STREAM STATIONS (mg/l)

Station	Water Year	Flow (l/s)[a]	pH	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn
MS-1	1976	48.7	6.6	8	7	0.02	1.1	0.02	0.1	0.1
	1977	32.6	7.2	8	10	0.02	0.9	0.01	0.2	0.1
	1978	73.9	6.9	9	16	0.04	1.3	0.01	0.2	0.2
	1979	66.6	6.4	25	13	0.05	1.6	0.01	0.1	0.2
	1980	50.8	6.6	10	11	0.04	1.3	0.01	0.1	0.2
MS-2	1976	54.9	5.4	22	93	0.15	2.3	0.03	0.8	5.9
	1977	36.3	5.3	89	321	0.82	3.5	0.20	2.5	18.3
	1978	87.2	5.7	27	80	0.14	1.6	0.02	0.6	4.6
	1979	82.4	5.9	38	81	0.09	1.5	0.02	0.7	5.0
	1980	68.2	5.8	29	166	0.15	1.6	0.03	0.8	8.1
MS-3	1976	94.3	4.9	21	131	0.26	3.3	0.09	2.3	4.7
	1977	62.6	5.3	38	192	0.30	1.7	0.05	3.1	5.8
	1978	140.2	4.9	28	120	0.22	1.7	0.03	1.5	3.7
	1979	140.5	5.0	41	116	0.14	1.4	0.02	1.6	3.4
	1980	115.5	5.3	19	124	0.23	1.5	0.02	1.9	3.4
MS-4	1976	147.8	3.9	134	240	0.95	37.3	0.07	2.1	4.8
	1977	94.6	3.8	238	376	1.73	54.9	0.13	2.5	7.9
	1978	206.5	3.7	160	224	1.17	31.3	0.07	1.6	5.7
	1979	198.8	3.6	217	196	0.79	25.5	0.07	1.7	4.3
	1980	153.1	3.8	178	255	0.78	29.0	0.04	1.9	4.5
MS-5	1976		3.4	173	241	1.28	33.8	0.08	1.9	4.6
	1977		3.4	322	468	3.22	58.0	0.13	2.7	8.3
	1978		3.4	183	246	2.11	38.6	0.07	1.6	5.6
	1979		3.3	236	178	1.19	24.9	0.07	1.7	4.0
	1980		3.4	216	328	1.15	27.0	0.47	2.2	4.6

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[a] No continuous flow records available for MS-5.

TABLE 66. AVERAGE ANNUAL LOADS BY WATER YEAR AT MS-1, MS-2, MS-3, and MS-4 (kg/d)[a]

Station	Water Year	Flow (l/s)	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn
MS-1	1976	48.7	43	34	0.09	3.7	0.03	0.4	0.3
	1977	32.6	85	21	0.03	2.5	0.04	0.4	0.2
	1978	73.9	63	66	0.30	6.1	0.04	0.9	1.1
	1979	66.6	184	97	0.41	6.9	0.08	0.8	1.9
	1980	50.8	41	55	0.20	5.0	0.03	0.6	0.9
MS-2	1976	54.9	83	306	0.54	8.8	0.10	2.4	18.5
	1977	36.3	82	311	0.58	8.2	0.26	3.2	24.7
	1978	87.2	193	479	0.97	11.2	0.15	3.7	26.5
	1979	82.4	321	432	0.73	9.3	0.20	3.6	26.4
	1980	68.2	96	400	0.51	9.6	0.09	3.0	23.8
MS-3	1976	94.3	137	830	1.8	26.0	0.55	13.4	30.5
	1977	62.6	132	540	1.1	11.3	0.18	8.5	22.0
	1978	140.2	320	1177	2.0	21.2	0.36	15.5	39.5
	1979	140.5	617	1026	2.0	19.3	0.32	15.1	32.2
	1980	115.5	160	699	1.4	16.9	0.16	12.5	27.5
MS-4	1976	147.8	1130	2188	8.4	313	0.6	18.5	46.0
	1977	94.6	1080	1709	8.8	371	1.0	14.2	46.5
	1978	206.5	2421	3242	18.9	493	1.4	26.2	87.5
	1979	198.8	3186	2663	11.4	354	1.0	20.7	58.5
	1980	153.1	1543	2300	7.7	281	0.4	17.8	46.3

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[a] No continuous flow records available at MS-5.

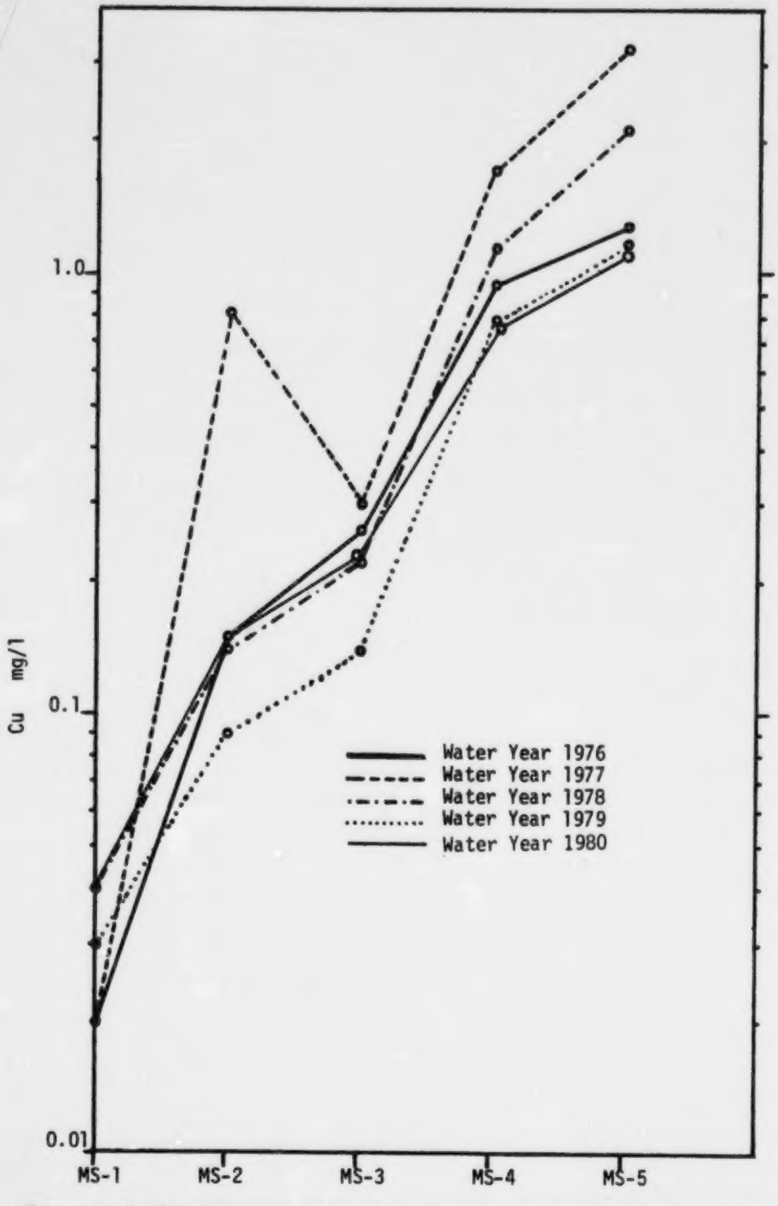

Figure 105. Comparison of average copper concentrations by water year at affected stream stations.

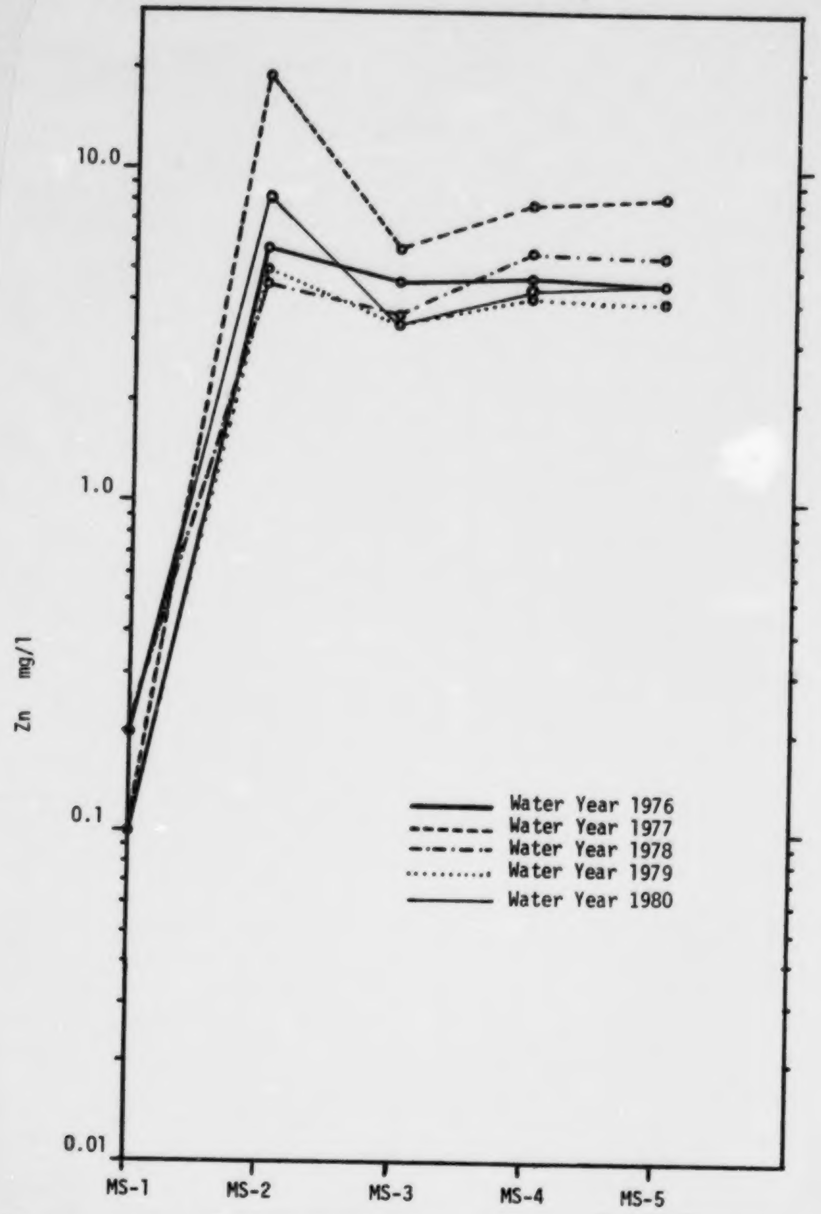

Figure 106. Comparison of average zinc concentrations by water year at affected stream stations.

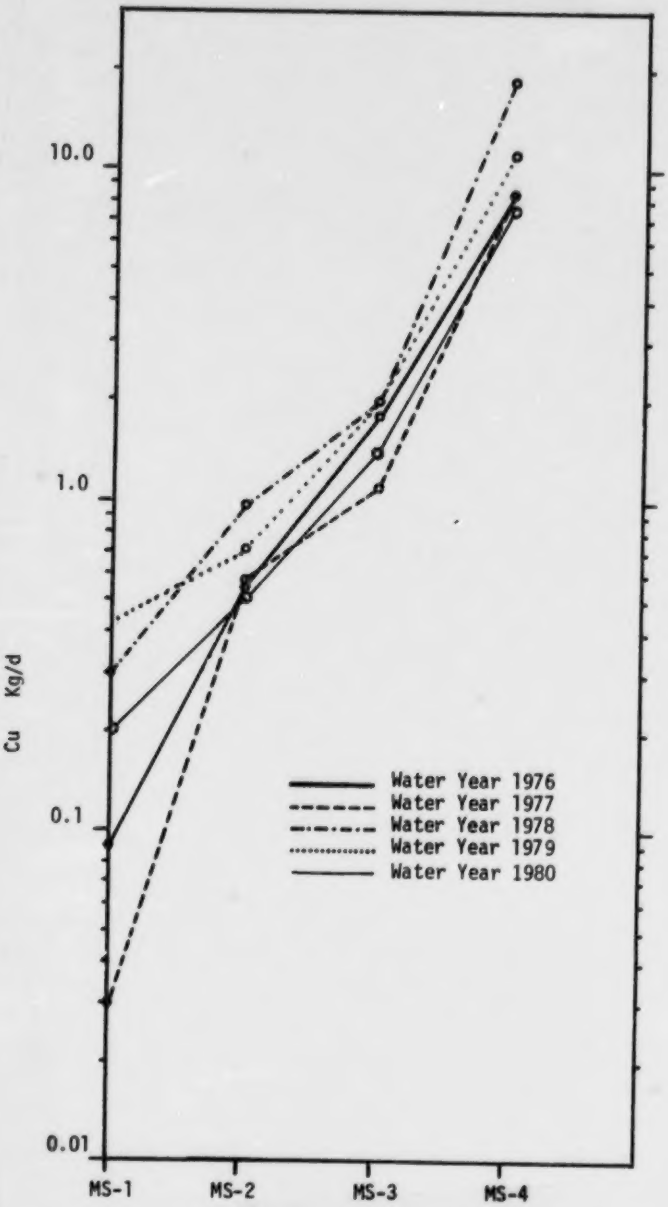

Figure 107. Comparison of average copper loads by water year at affected stream stations.

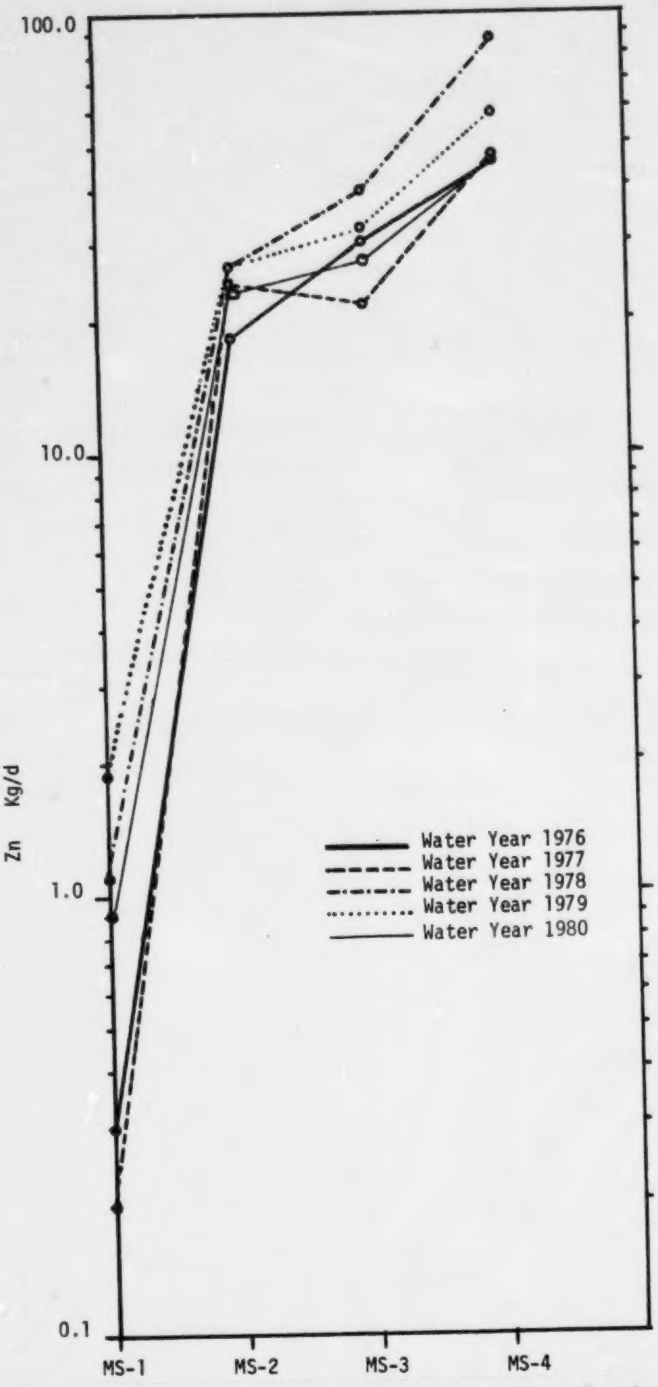

Figure 108. Comparison of average zinc loads by water year at affected stream stations.

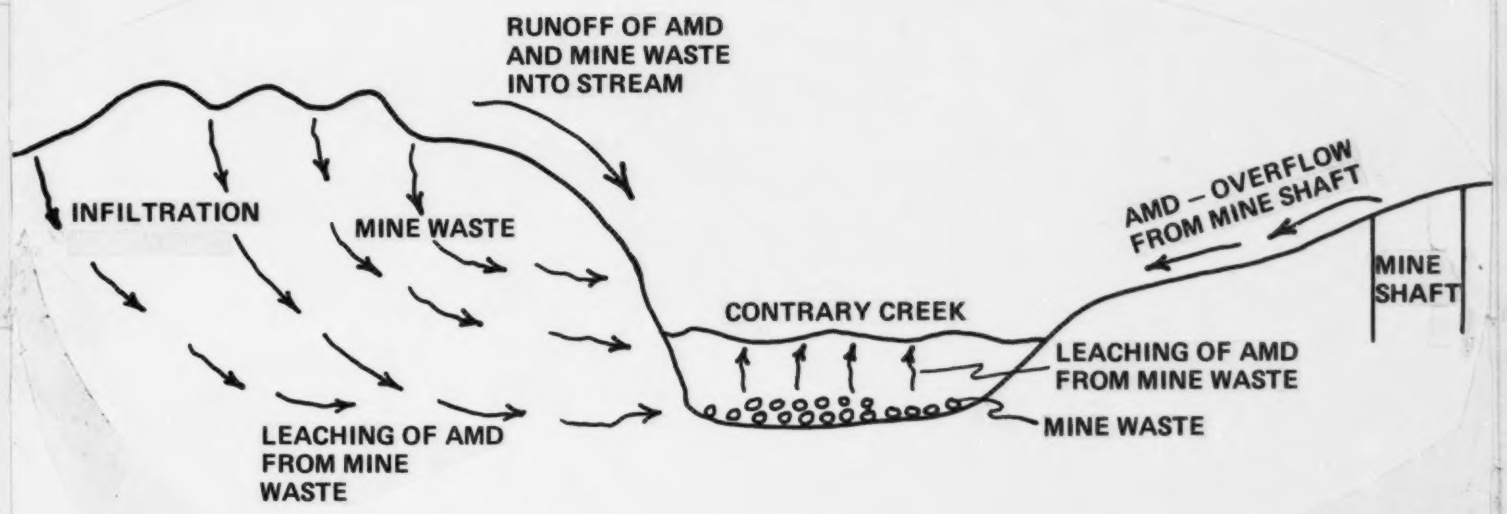

FIGURE 109. SOURCES OF ACID MINE DRAINAGE INTO CONTRARY CREEK

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thus reduce the formation of AMD by development of a soil cover with vegetation.

4. The sludge and limestone added to the mine waste would neutralize and treat the AMD previously generated in the mine waste and reduce further generation.

The reduction of erosion and transport of mine waste into the stream and the reduction of overland flow of AMD to the stream has been accomplished. Erosion control was discussed on page 88. Since the surface soil now has a higher pH and lower concentration of heavy metals (Table 34, P.97), the runoff quality is undoubtedly improved. Thus, the remaining major sources of AMD are the mine waste in the stream bed and the leaching of the mine waste material. There is no way to measure the contributions each of these AMD sources has to the overall problem. Some indication of the contribution that the mine waste deposited in the stream bed has on water quality can be seen by comparing the load data from MS-4 and MS-5 on a date when flows were extremely low in the summer of 1977 (Table 67). The only source of AMD in this section of the stream is the deposited mine waste. Although some mine waste was removed from the stream in the vicinity of the Sulphur Site, large quantities still remain and the reduction from this source of AMD is probably insignificant if at all.

TABLE 67. COMPARISON OF LOADS AT MS-4 AND MS-5 ON BASIS OF INSTANTANEOUS FLOWS ON AUGUST 18, 1977 (Kg/d)

Station	Flow(l/s)	Acidity ($CaCO_3$)	SO_4	Cu	Fe	Pb	Mn	Zn
MS-4	3.40	6489	411	1.4	44	0.07	1.8	4.7
MS-5	5.66	18490	979	5.4	98	0.18	3.8	17.6

The impact of regrading, vegetation establishment, and addition of sludge and limestone on the leaching of the mine waste will require several years to document. There is no way to actually measure the quality and quantity of leachate reaching the stream, thus the impact must be measured by monitoring the stream. As noted, to date the monitoring data indicates there has been little improvement in the water quality. This result may mean that the stream bed source is the overriding factor. However, if we look at Table 57, we see that the specific conductance increases 125 units between 1200 and 2100 meters or an increase of 0.14 unit per meter of stream. The only contribution in this area is mine waste in the stream bed. If we assume this to be the rate of release by stream bed material then the release for the 800 meters of stream through the Sulphur Site would be 112 units. However, the actual increase is 553 units. Thus, we can conclude that the major source is the AMD leaching from the mine waste banks. (See Study by Nordstrom in Appendix D).

Because of the long existence of the mine waste banks, we can assume that they are saturated with pyrite oxidation products - AMD. Thus, even if all new production of AMD was eliminated, a significant time would be required to leach the AMD material from the mine waste. The reduction in inflitration will only extend this time period. The effectiveness of the soil cover in reducing acid production is surely debatable, and several years will be required to collect the information needed to make any conclusions based on stream water quality. The sludge and limestone applied to the mine waste should neutralize some of the AMD in place. Several years may be required for this chemical front to move through the mine waste and be reflected in stream water quality.

So far as can be determined, from BOD and fecal coliform analyses, the extensive use of wastewater sludge at all three mine sites has not affected the water of Contrary Creek or Lake Anna in any adverse manner nor created any health hazards. The Contrary Creek arm of Lake Anna is obviously degraded by AMD as far out as SS-1 in the lake, but the main body of the reservoir appears to be unaffected. The lake abounds in sport fish, and there have been no known detrimental effects by AMD on the nuclear power plant which uses the reservoir for cooling water.

In conclusion, rapid changes in water quality cannot be expected to show up in Contrary Creek. Several more years of monitoring will be required to evaluate the effectiveness of the remedial action.

BIOLOGIC STUDIES

Both prereclamation and postreclamation biologic studies have been conducted and are continuing semiannually. As stated in Section 3, ecological surveys of Contrary Creek and the North Anna River were performed by VPI&SU prior to the construction of Lake Anna which showed aquatic life to be severely affected by AMD, and revealed that the North Anna River did not fully recover for at least 8.7 kilometers (14 miles) downstream. All subsequent biologic studies have been conducted by the DES of the SWCB. A prereclamation survey of the Contrary Creek arm of Lake Anna by the DES in the spring of 1974 is summarized in Section 10 and the complete report appears in Appendix D.

After the reclamation work in 1976 the DES conducted cursory benthic surveys of Contrary Creek each fall and spring except for the fall of 1977. Quantitative samplings were done each spring from 1978 to 1980. The cursory investigations consisted of walking the stream and qualitatively appraising the kinds and numbers of benthic invertebrates present on rocks, twigs, leaves, and other vegetative debris in riffle areas at each station. For the quantitative samplings a Surber square foot sampler was used to collect benthics at each station and organism counts were made. Tests for pH and dissolved oxygen along with temperature readings were made during each survey. Figure 110 shows locations of the sampling stations. BS-1A was not included in the first survey.

The first cursory survey was conducted in October 1976. No benthic life was found in Contrary Creek at BS-1 below the Sulphur Site. This sterile

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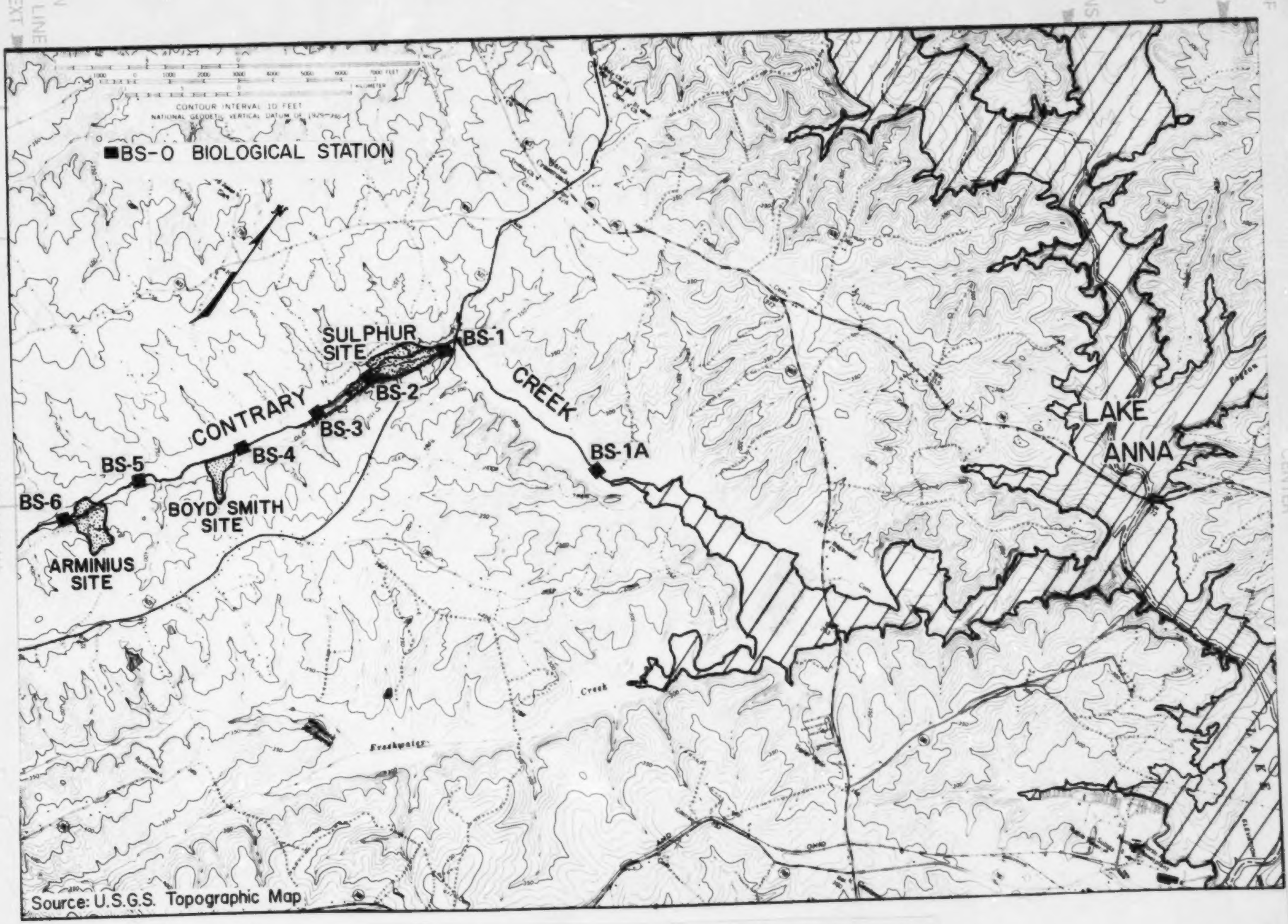

Source: U.S.G.S. Topographic Map

FIGURE 110 . CONTRARY CREEK BIOLOGICAL STATIONS

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condition was in part attributed to the heavy coating of ferric hydroxide [$Fe(OH)_3$] that covers the substrate throughout much of the stream as it flows through the Sulphur Site. Ferric hydroxide smothers benthic organisms which breathe through gills and covers the habitat of others. Of course the high acidity alone is enough to render the stream sterile.

At BS-2 which is located within the Sulphur Site, a few tolerant and facultative forms of benthics were observed, but most were on vegetation hanging down into the water rather than in the stream bed. Colonies of filamentous bacteria were found in pools but lack of periphytic algae gave the rocks a sterile appearance. The prevalance of toxic conditions was evidenced by the low density and moderate diversity of organisms.

A low-density population of benthos was found at BS-3 which is in a wide gravel bar just upstream of the Sulphur Site. Caddisflies were observed here, but most organisms were still on leaves rather than on rocks, and filamentous bacteria were again abundant in pool areas. At BS-4 immediately below the Boyd Smith Site more facultative forms were found along with a few sensitive types. Although the density of populations was still low, the shift toward more sensitive organisms was encouraging.

BS-5 is approximately midway between the Arminius and Boyd Smith Sites in a shaded reach of the stream. Here benthic populations were considered to be a step closer to normal conditions for a clean stream. Diversity of organisms remained high and sensitive forms were more abundant. However, the density of the population was still far below normal and the lack of periphyton still gave the substrate a sterile look. Most organisms were found on vegetative matter.

At the control station BS-6 just upstream from the Arminius Site and above all of the affected reach of Contrary Creek, the most notable change was the dense growth of periphyton on rocks in the stream. Periphytic life was non-existent at all stations at and downstream from the Arminius Site. Both density and diversity of benthic life increased at the control station and more sensitive types were found. This was the only part of the stream where minnows were seen and neither hydroxide nor filamentous bacteria were present.

In summary there was a gradual progressive improvement in benthic populations upstream to the control station but even BS-5 below Arminius was seriously degraded. The change from tolerant and facultative forms to more sensitive forms was most apparent, and only at the control station did the density of benthics increase enough to assume that they represented a reproducing resident community. Absence of periphyton in the affected part of the stream was a clear indicator of toxicity resulting from AMD. Results of the October 1976 survey are shown in Table 68.

The second cursory survey conducted in April 1977 began with an additional station BS-1A, at the mouth of Contrary Creek. Here the stream is bordered by a wide barren floodplain of sediments that have been washed downstream. Riffle areas are poorly developed and pools are shallow with hydroxide covering much of the substrate. Low numbers of tolerant organisms comprise the

TABLE 68. CURSORY BIOLOGIC SURVEY - OCTOBER 1976

Station	DO mg/l	pH	Temp. °C	Stream Size W x D	Substrate	Macrobenthic Invertebrates [a]	Comments
BS-1	2.2	4.5	19	5m x 10cm	$Fe(OH)_3$ Sand Rocks	one bloodworm	$Fe(OH)_3$ covering bottom, only life found in runoff pool below sludge bank.
BS-2	6.6	4.3	19	4m x 15cm	Sand Gravel Roots Rocks $Fe(OH)_3$	Hellgrammites C Dragonflies F Hemiptera F Whirlegig beetle F Midges F	Very little $Fe(OH)_3$ much more benthic life, mostly on roots not rocks, filamentous bacteria in pools.
BS-3	8.0	5.0	22	2m x 10cm	Rocks Gravel Leaves	Whirlegig beetle C Caddisflies F Dragonflies F Hellgrammites F Hemiptera F Midges F	Poor riffle, most benthics on leaves, filamentous bacteria in pools.
BS-4	8.8	5.0	19	3m x 10cm	Bedrock Rocks Gravel Leaves	Caddisflies C Flatworms F Hellgrammites F Water pennies F Riffle beetles F Midges F	Good riffle, benthic density still low but more sensitive forms present.

(continued)

TABLE 68. (continued)

Station	DO mg/l	pH	Temp. °C	Stream Size W x D	Substrate	Macrobenthic Invertebrates [a]	Comments
BS-5	8.4	5.3	16	2.6m x 8cm	Bedrock Rocks Gravel Roots Leaves	Hellgrammites F Water pennies F Hemiptera F Caddisflies F Bloodworms F Stoneflies F Midges F	Woodland area, most benthics on leaves, density still low, bacteria in pools.
BS-6	9.6	6.8	16	2m x 10cm	Bedrock Rocks Gravel Leaves	Caddisflies C Water pennies C Leeches F Crayfish F Stoneflies F Mayflies F Riffle beetles F Midges F	Good riffle, more periphyton, benthics on rocks, density increased. Minnows seen.

[a] Letters denote relative abundance: D - dominant A - abundant C - common F - few

benthic community here. The conditions at BS-1 thru BS-5 were generally the same as those observed during October 1976. Benthic populations were dominated by tolerant and facultative forms with a few sensitive types noted at BS-4 and BS-5. Fewer dragonfly nymphs and caddisfly larvae were observed than the previous October, but more bacteria growth was observed. Compared to the first survey there was a pronounced decline in the benthic community density at BS-5 below the Arminius Site. This decline may have been partly due to seasonal changes. A healthy stream biota was again observed at the control station.

The first quantitative sampling by the DES in conjunction with a cursory survey in April 1978 indicated that the status of aquatic life in Contrary Creek had actually deteriorated since the spring of 1977. The study revealed a decline in density of organisms at all stations in the affected reach of the stream, and there was even a reduction in density and diversity of macroinvertebrates and in periphyton growth at the control station. It is likely that the extreme low flow during the severe drought of the previous season was a factor because this would have reduced the number of organisms drifting downstream and would have reduced the habitat available for colonization.

The October 1978 cursory survey showed some increases in aquatic life in Contrary Creek for the first time, but toxicity was still having a severe effect along much of the stream. A dense population of bloodworm midge larvae were found to have established at BS-1A just above the confluence of Contrary Creek with Lake Anna. These organisms are pollution tolerant, but it was the first time any kind of life had been found at this station.

At BS-1 filamentous algae and diatoms were observed on a few rocks and green algae were present in shallow pools along the stream banks. Bloodworm midges were also found at this station in sand and gravel bars and on the hydroxide-coated rocks. The presence of bloodworms may have resulted from the nutrients contributed by the sludge used in the reclamation work. BS-2 within the Sulphur Site was found to have more aquatic life than during earlier investigations. A few facultative forms were present in low numbers and the benthic community was again dominated by bloodworms. At BS-3 the benthics appeared much healthier than in earlier surveys. Facultative and tolerant organisms were dominant but a few sensitive forms were also found.

Below the Boyd Smith Site at BS-4 facultative forms dominated the benthic community and bloodworm populations were found to be lower than at the downstream stations. An encouraging note was an increase in caddisfly populations. The benthic community at BS-5 below the Arminius Site was not as diverse as at BS-3 or BS-4, and bloodworms were again the most abundant organism. Heavy deposits of iron bacteria were found in pools and noted to be thicker than in previous surveys. The control station was dominated by facultative and sensitive organisms and a moderate diversity of forms. Benthics were much more abundant than in the previous survey in April 1978.

The spring of 1979 study consisted of another quantitative sampling with the regular cursory survey. Although the cursory survey revealed more types of organisms than the quantitative sampling, there was really no improvement noted in the biota of the affected portion of Contrary Creek since the previous year. Results of both surveys appear in Table 69.

Another cursory benthic survey was conducted in October 1979. At this time, as before, the upstream control station appeared to be in good condition. The aquatic life community was similar to past observation with sensitive organisms dominating a diverse assemblage of macroinvertebrates. At BS-5 below the Arminius site, water quality was poor with a few facultative and tolerant organisms present. The dissolved oxygen and pH were not prohibitively low at this station but the AMD was definitely limiting the benthic life. The benthic community at BS-4, below the Boyd Smith mine site, was more diverse than it had been previously but the populations were still lower than at the control. Water quality at BS-4 was rated fair to poor, an improvement over BS-5 and earlier BS-4 results.

The diversity of benthic types at BS-3 upstream from the Sulphur Site was higher than it had been the previous spring and compared favorably with conditions observed in the fall of 1978. The density of organisms and the relative abundance of sensitive forms were not comparable to conditions at BS-6 however, and water quality was rated fair. From BS-2 downstream, the substrate remained covered with a thick ferric hydroxide precipitate which fills in the benthic habitat and smothers all but the most tolerant species. There was also a 2.0 mg/l drop in dissolved oxygen and a 1.1 unit drop in pH observed at this station. Most of the organisms observed at BS-2 were found among the streambank grasses rather than on the bottom itself. There were facultative forms which seem to be able to tolerate the poor water quality found in this area. These poor water quality and habitat conditions persisted downstream through the area of BS-1.

A third quantitative survey conducted in the spring of 1980 showed that macroinvertebrates were still very sparse in the affected portion of the stream. Although no significant improvement in biologic conditions was noted, there was an increase in dissolved oxygen and pH at stations BS-1A, BS-1, and BS-2, which was encouraging. There was also less ferric hydroxide precipitate observed on the substrate in the vicinity of the Sulphur Site. Results of the 1980 spring survey are shown in Table 70.

Summary Of Biologic Studies

The overall assessment of the biologic studies to date is that the toxic conditions that have apparently prevailed in Contrary Creek for nearly one hundred years rendering it virtually devoid of aquatic life have remained essentially unchanged within the relatively short time interval that has elapsed since reclamation began. There have been slight improvements in the benthic communities between the Boyd Smith and Sulphur Sites, but most of the other stream reaches below the mine sites, especially the lower end, remain highly toxic to all but the most tolerant organisms.

TABLE 69. CURSORY AND QUANTITATIVE BIOLOGIC SURVEY - MAY 1979

Station	DO mg/l	pH	Temp ^oC	Stream Size W x D	Substrate	Macrobenthic Invertebrates [a]		Number Macrobenthic Invertebrates [b]		Comments
BS-1A	5.2	4.0	27	6m x 8cm	Boulders Rocks Gravel Sand $Fe(OH)_3$	Hemiptera Bloodworms Whirlegig Beetle Alderfly	C F F X	None		Light growths of filamentous algae and periphyton. Less $Fe(OH)_3$ than at BS-1. Fewer midges than previous year, poor water quality.
BS-1	4.8	4.3	24	5m x 10cm	Bedrock Boulders Rocks Gravel Sand $Fe(OH)_3$	Hemiptera Bloodworms Whirlegig Beetle	C F F	Diptera Ptychopteridae	 1	Bacteria and green algae in side pools. $Fe(OH)_3$ coats entire substrate, poor water quality.
BS-2	5.0	4.5	29	6m x 15cm	Rocks Gravel Leaves Roots Clay $Fe(OH)_3$	Hemiptera Hellgrammites Bloodworm	F F X	Diptera Chironomus sp. Megaloptera Corydalus cornutus	 1 1	Very little algae, bacteria thick in pools, poor water quality.
BS-3	6.6	6.3	27	5m x 15cm	Bedrock Boulders Rocks Gravel Sand	Hellgrammites Hemiptera Whirlegig Beetle	F F F	Megaloptera Corydalus cornutus Diptera Chironomus sp.	 2 1	Filamentous algae moderate in riffle. Bacteria thick in pools. Poor water quality. pH & DO higher than downstream.
BS-4	7.1	6.5	24	5m x 10cm	Bedrock Boulders Rocks Gravel Sand	Hemiptera Hellgrammites Water Penny Alderfly Beetle Midge	C F X X X X	None		Filamentous algae and bacteria moderate. $Fe(OH)_3$ thin coating on rocks.

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[a] D - dominant A - abundant C - common F - few X - present

[b] Each sample is from one Surber square foot sampler.

TABLE 69. (continued)

Station	DO mg/1	pH	Temp oC	Stream Size W x D	Substrate	Macrobenthic Invertebrates		Number Macrobenthic Invertebrates		Comments
BS-5	7.1	7.0	22	3m x 15cm	Bedrock Boulders Rocks Gravel Sand	Hemiptera Caddisfly Stonefly Diptera Dragonfly Water Penny	F F F F X X	Diptera Ptychopteridae Plecoptera Acroneuria sp. unidentified Hemiptera unidentified Coleoptera Brychius sp.	 1 2 1 1 1	Light filamentous algae in riffles, thick bacteria in pools, $Fe(OH)_3$ thin coating on rocks. Poor water quality.
BS-6	8.0	7.5	19	4m x 10cm	Bedrock Rocks Gravel Sand Detritus	Stoneflies Caddisflies Blackflies Water Pennies Crayfish Mayflies Riffle Beetles Midges Hemiptera Dragonfly Flatworm Cranefly	C-F F-C F-C F F F F F F X X X	Diptera Simulium venustum Simulium vittatum Tipula sp. Limnophilia sp. Polypedilum sp. Orthocladinae Chironominae Coleptera Elmidae Ptilodactylidae Plecoptera Nemoura venosa Acroneuria arenosa Trichoptera Hydropsyche sp. Megaloptera Corydalus cornutus Hemiptera Gerris sp. Ephemeroptera Pseudocloeon sp. Isonychia sp.	 47 1 1 1 1 2 1 4 1 12 2 7 1 1 1 1	Light filamentous algae. Diatom coating on rocks. Low density, high diversity. Fair to good water quality.

TABLE 70. QUANTITATIVE BIOLOGIC STUDY - APRIL 1980

Station	DO mg/l	pH	Temp. °C	Stream Size W x D	Substrate	Number of Macrobenthic Invertebrates[a]	Comments
BS-1A	8.0	4.7	16	6m x 8cm	Gravel Rocks Sand Silt $Fe(OH)_3$	None	Some algae on rocks.
BS-1	7.8	4.7	18	5m x 10cm	Gravel Sand Rocks Some $Fe(OH)_3$	(Adult Diptera) 2	Slight algae.
BS-2	9.2	5.0	18	6m x 15cm	Gravel Rocks Sand Roots $Fe(OH)_3$	Diptera *Simulium* sp. 1 Megaloptera *Nigronia* sp. 1	Side tributary pH 4.7.
BS-3	10.5	6.5	13	5m x 15cm	Bedrock Boulders Rocks Gravel Sand	Diptera *Heterotrissocladius* sp. 1 Megaloptera *Nigronia* sp 4	Moderate algae, willows & pines, riffle/pool.
BS-4	9.8	6.1	14	5m x 10cm	Bedrock Gravel Rocks	Plecoptera *Acroneuria* sp. 1	Moderate algae.
BS-5	10.0	6.5	12	3m x 15cm	Bedrock Rocks Gravel Sand	Megaloptera *Nigronia* sp. 1 *Sialis* sp. 1	Some algae,no diatoms.

(continued)

TABLE 70. (continued)

Station	DO mg/l	pH	Temp. oC	Stream Size W x D	Substrate	Number of Macrobenthic Invertebrates		Comments
BS-6	10.2	7.0	11	4m x 10cm	Bedrock	Diptera		Moderate algae and diatoms.
					Rocks	Simulium sp.		
					Gravel	(larvae)	172	
					Sand	Simulium sp.		
					Detritus	(pupae)	2	
						Polypedilum sp.	4	
						Microspectra sp	3	
						Eukiefferiella sp	2	
						Rheotanytarus sp	2	
						Chironomidae		
						larvae	1	
						Trichoptera		
						Rhyacophila sp.		
						(pupae)	4	
						Hydropsyche sp.	2	
						Potamyia sp.	2	
						Ephemeroptera		
						Stenonema sp.	1	
						Plecoptera		
						Acroneuria sp.	4	
						Amphinemura sp.	4	
						Isoperla sp.	1	
						Isogenus sp.	1	

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[a] Each sample is from one Surber square foot sampler.

SECTION 10

SPECIAL STUDIES

Four special studies associated with the Contrary Creek Project are discussed in this section. The first is a 1977-78 water quality study done to identify specific sources of AMD in the project area and to examine the effects of storm runoff on the chemistry of Contrary Creek. The second is a 1974 prereclamation biologic study of the Contrary Creek Arm of Lake Anna. The other studies are of test plots planted at the Arminius Site in 1974-75 and a 1978 metals uptake study of vegetation at the Sulphur and Boyd Smith Sites.

WATER QUALITY STUDY BY UNIVERSITY OF VIRGINIA

During 1977 and 1978 the Department of Environmental Sciences of the University of Virginia conducted a special water quality study of Contrary Creek entitled "Major Sources of Acid and Heavy Metals Which Contribute to the Acid Mine Waters of Contrary Creek, Louisa County, Virginia." This study was funded from the EPA demonstration grant with the SWCB providing assistance in field investigations. The complete text of this report can be found in Appendix D.

The objectives of the study were:

1. To identify the specific sources of AMD along Contrary Creek and the relative importance of each source.

2. To determine how pH and metal concentrations vary during a rainstorm and what factors cause these variations.

3. To determine if a heavy rainstorm causes substantial increases in metal loads.

4. To determine how heavy metals are partitioned between dissolved and particulate phases and if there are substantial changes during a rainstorm.

To carry out this study it was proposed that detailed sampling of Contrary Creek and its tributaries in the vicinity of the mine sites be conducted during low flow and changing flow, i.e., a rainstorm event. During a dry period efflorescent sulfates were to be collected from the surface of the mine wastes and analyzed for mineralogical and chemical composition. The occurrence and distribution of these soluble salts were to be correlated with the major points of metal input during a rainstorm. Water samples were to be collected and flow measurements were to be made at all regular monitoring stations along Contrary Creek except MS-5, at two tributary stations of the Sulphur Site, and at six tributary stations of the Boyd Smith Site. Two longitudinal transects were to be made along each side of the Sulphur Site to pinpoint major metal discharges. During a rainstorm water samples and flow measurements were to be conducted at the four regular monitoring stations at the Sulphur, and the three tributary stations at the Boyd Smith. Two additional tributary stations were to be sampled and measured at the Boyd Smith provided manpower was available. Automatic samplers were to be used at two of the regular stations with the other two to be sampled manually.

With the approval of the EPA Project Officer, a $14,148 grant was awarded for conducting the study from the Contrary Creek EPA demonstration grant. The original grant period was to be from June 1977 to May 1978, but it was impossible to complete this study during this period because there was no measurable flow in many of the tributaries during the drought of 1977 and conditions were not opportune for a rainstorm study. In light of these circumstances, the project was extended for another year and an additional $2640 was included in the grant to cover costs associated with the extension.

The only part of the study completed in 1977 was a survey of the efflorescent sulfate minerals forming during dry weather on the mine wastes along the stream banks. During 1978 several attempts were made to conduct a full-scale rainstorm event study as proposed, but due to the unpredictable nature of the storms and the logistics of getting personnel from several distant places on site at the optimum time, it was not possible to achieve this. However, six partial rainstorm studies were conducted during 1978 in spite of the difficulties involved. During this period a specific conductance and pH transect was conducted at the Sulphur Site along with investigations of acid seep pools in Contrary Creek at the Sulphur Site and a study of the diurnal variation in water chemistry of the stream.

A brief summary of the results of this study are:

1. Sources of AMD are of three types: (a) mine effluents, (b) acid seeps from the base of tailings piles and (c) soluble hydrated sulfate minerals occurring at the surface.

2. Only two effluents were identified as issuing from mine shafts and both contribute only small proportions of the total AMD loads.

3. Acid seeps from the base of tailings piles contribute the major portion of AMD during dry periods between storm events.

4. AMD is stored as soluble sulfate minerals in the top layer of mine tailings during dry periods. During storm events the major portion of pollutants is derived from the dissolution and rapid flushing out of these sulfates. The longer the dry period, the greater the increase in metal concentrations when the rainstorm occurs.

5. Conductivity and pH transects showed where major increases in dis-

solved solids occur and indicated where additional reclamation may be needed. The final report on this study was submitted to EPA and the SWCB in late 1979.

BIOLOGIC STUDY OF CONTRARY CREEK ARM OF LAKE ANNA

During the spring of 1974 the DES conducted a survey of the Contrary Creek arm of Lake Anna to characterize the biota and heavy metals content of the bottom sediments. Algae and macrobenthos and sediments were collected from seven stations along with physical and chemical testing of water. Four of the stations were in the affected part of the Contrary Creek arm and three stations were sampled in nearby unaffected parts of the lake. The study which is the only one to date of the Contrary Creek arm revealed that benthic populations were generally low in diversity and density in the affected portion and showed a definite reduction in productivity. The populations were probably affected as much by substrate composition as by AMD. Algal population data clearly indicated toxic conditions and a pH and dissolved oxygen gradient was noted from the mouth of Contrary Creek for approximately 3 kilometers out into Lake Anna. Abnormally high levels of heavy metals were found in the bottom sediments with zinc and copper concentrations exceeding levels previously associated with fish kills. Although fish had invaded the Contrary Creek arm, the populations were found to be less dense and diverse than the main body of the lake. Analyses of fish tissue revealed concentrations of heavy metals in appreciable amounts, and the study warned that the fish were taking up metals in amounts that should be monitored. This report in its entirety appears in Appendix D.

REVEGETATION STUDIES AT ARMINIUS SITE

Three sets of test plots were planted at the Arminius Site in 1974 and 1975 prior to reclamation to study the growth and survival of different plant species using various rates of soil additives and with no soil additives. This study was by A. Chandler Mortimer, Consultant for Callahan Mining Corporation. See Appendix D for a report on the study.

METALS UPTAKE BY VEGETATION - NOVEMBER 1978

In the fall of 1978 the EPA contracted Hittman Associates, Inc. to conduct a study of metals uptake in the vegetation growing on the Sulphur and Boyd Smith Sites. This contract was not funded from the demonstration grant. Composite samples of the various plant species were collected in early November 1978 from areas of both established growth from the first two years of work and new growth from the most recent fall seeding. Samples consisted only of the above-ground portions of the plants and care was taken to prevent any metal contamination from the soil. A control sample was collected from an undisturbed area of indigenous vegetation. Table 71 depicts plant species present and per cent of cover at each sampling site as described by the testing firm. Laboratory procedures are discussed in Appendix B.

TABLE 71. SPECIES MIX AND PER CENT COVER-METALS UPTAKE STUDY-NOVEMBER 1978

Area	Species Mix	% Total Cover
Sulphur West		
Control Area	Escaped grasses	100
Tailing Area (Established Growth)	Clover (3%), Rye (47%) Fescue (50%)	90
Tailing Area (New Growth)	Rye (66%), Fescue (33%) Clover (1%)	10
Sulphur East		
Large Area (New Growth)	Rye (50%), Fescue (50%)	10
Large Area (Established Growth)	Lovegrass (20%), Fescue (80%)	90
Upstream Flat (Established Growth)	Lovegrass (50%), Rye (20%) Fescue (30%)	50
Tipple Area (Established Growth)	Lovegrass (15%), Fescue (85%)	95
North End (New Growth)	Rye (70%), Fescue (30%)	5-15
Boyd Smith		
Small Area of sparse growth	Fescue (85%), Lovegrass (15%)	5
Established Growth	Fescue (85%), Lovegrass (15%)	90

Modified after Hittman Associates, Inc., (1979).

The results of the metals uptake study are presented in Table 72. The samples from established growth are generally indicative of the more successful areas while those designated as new growth represent the more troublesome areas that have required several seedings.

As can be seen from the data, there appear to be no distinct trends, although some metals tend to be higher from the more severe areas. Lead seems to reflect this pattern more so than the other metals. In the Tailing

TABLE 72. METALS UPTAKE OF VEGETATION (ug/g)

Area	As	B	Cd	Cr	Cu	Fe	Hg	Mn	Ni	P	Pb	Se	Zn
Sulphur West													
Control Area	0.2-[b]	300	0.1-	0.1-	6.7	220	0.1-	155	1.0	50	0.1-	0.1-	60
[a]Tailing Area (Established Growth)	0.2-	900	0.03	1.3	26	500	0.1-	340	4.6	60	0.6	0.1-	80
Tailing Area (New Growth)	0.2-	1400	0.1-	0.1-	9.0	1300	0.1-	120	6.6	300	4.8	0.1-	60
Sulphur East													
[a]Large Area (New Growth)	0.2-	500	0.4	1.8	17.6	330	0.1-	240	2.1	345	0.8	0.6	40
Large Area (Established Growth)	0.2-	700	0.2	0.09	3.6	86	0.1-	320	1.2	170	0.1-	0.4	40
Upstream Flat (Established Growth)	0.2-	400	2.5	1.9	21	160	0.1-	600	4.3	140	0.1-	0.3	1200
[a]Tipple Area (Established Growth)	0.2-	450	0.4	0.4	7.8	160	0.1-	300	3.2	100	0.1-	0.2	70
North End (New Growth)	0.2-	900	0.3	0.2	36	180	0.1-	410	6.3	410	0.7	1.2	3100
Boyd Smith													
Small Area of sparse growth	0.2-	800	1.5	4.3	20.9	1700	0.1-	760	8.3	180	3.5	0.1-	400
[a]Established Growth	0.2-	700	2.5	0.7	18.8	70	0.1-	470	2.1	240	0.1-	1.2	360

Source: Hittman Associates, Inc. (1979).

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[a] These samples are averages of duplicates.

[b] A (-) sign indicates that the concentration was below the indicated level of detection.

Area of Sulphur West copper was found to be about three times higher in established growth than in new growth, but in the Large Area of Sulphur East copper was over four times higher from new growth than from established growth. The two relatively high zinc values of 1200 ug/g and 3100 ug/g were respectively from established growth on the Upstream Flat, a moderately successful area, and from new growth on the North End, one of the more severe areas. Iron values covered a wide range with the maximum from a small barren spot at the Boyd Smith Site and the minimum from well established growth at the same site. Note that samples from five of the reclaimed areas showed higher iron content than the control. A comparison of Table 71 with Table 34, p.97 shows no apparent relationship between metals in the vegetation and soil, but it must be realized that data are too meager for a really valid test. The study recommended further testing for comparison of metals in the soil with those in the plants as well as a study to trace metals uptake through the food chain of mammals, but no further studies are planned at this time.

SECTION 11

SUMMARY OF PROJECT COSTS

This section summarizes the Federal and State costs expended on the Contrary Creek Project thru the end of FY 1980*. It will be recalled from Section 5 that the original grant agreement between EPA and the SWCB provided for 60 per cent funding by EPA with the SWCB providing 40 per cent matching funds by in-kind services. Under the terms of the agreement EPA was to grant up to $225,158 provided the SWCB matched this amount with the remaining 40 per cent of the total project cost. The original grant agreement was for a period of three years beginning in July 1975 and terminating in 1978. As discussed elsewhere in this report, it was necessary to extend the project due to great difficulty in establishing vegetation and abating the AMD problem. A summary of Federal costs or EPA grant funds is shown in Table 73.

Detailed cost breakdowns of reclamation and maintenance are presented in Sections 6 and 7 respectively. The $1006 for aerial photography was paid to the VDH&T for black and white, color, and infrared vertical coverage plus black and white and color oblique shots. The $890 for survey work was for close-interval contour mapping of the reclamation sites performed by the VDH&T prior to construction. The $80 for drafting was for preparation of plates and drawings used in the construction specifications which was done by a private firm contracted by the SWCB.

Table 74 summarizes SWCB matching costs expended from 1975 thru the end of FY80. Fringe benefits were computed by multiplying personnel costs by 23 per cent. Laboratory analyses costs include all water, sludge, and soil tests, and laboratory equipment costs were for four automatic flow recorders and repairs. Miscellaneous supplies include containers for sludge and soil samples, a winch purchased for the vehicle used in monitoring runs, no-trespassing signs, batteries, etc. The SWCB paid $27,500 for the feasibility study performed by Gannett Fleming Corddry and Carpenter prior to the reclamation work, but this was not part of the SWCB matching funds.

Total EPA and SWCB costs thru the end of FY 80 were:

EPA		$132,038
SWCB		163,296
	Total	$295,334

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*FY refers to the fiscal years used by the Commonwealth of Virginia, i.e. beginning July 1 and ending June 30.

TABLE 73.
SUMMARY OF FEDERAL FUNDS EXPENDED THRU FY 1980

1976 Reclamation Work		
Construction and seeding		$55,710
Stone		9,154
Straw bales		845
	Subtotal	$65,709
Maintenance		
Spring 1977		$20,809
Fall 1977		6,909
Spring 1978		1,222
Fall 1978		7,714
Spring 1979		3,829
Fall 1979		4,718
Spring 1980		2,687
	Subtotal	$47,888
Special water quality study by University of Virginia		$16,465
Aerial photography - 1978		$ 1,006
Prereclamation survey work		$ 890
Draft of construction plans		$ 80
	Grand Total	$132,038

This is around $81,000 less than the $376,661 originally estimated for a three-year period (see Table 5, Page 27). Major reasons for the lower costs were the free delivery of sludge to the project site by the District of Columbia and the much lower cost for 1976 reclamation work than anticipated. Pre-construction estimate for the construction work exclusive of cost of riprap stone was around $138,000. The low bid was approximately $88,000 and the work was actually done for around $56,000. Cost of riprap stone was estimated at $35,000 and actually cost less than $12,000 in the original reclamation work. With the additional $48,000 that was spent for maintenance after 1976 the total cost of reclamation including the survey work and drafting thru FY 1980 was $114,567.

Based upon this total figure for construction, seeding, and maintenance and the total of 19.5 acres measured as seeded in 1976, the average cost of reclamation at the end of FY 1980 was $5875 per acre or $14,518 per hectare. This includes all of the costs for riprap, straw bales for erosion control, and irrigation. Approximately 0.41 hectare of the Sulphur Site was never

TABLE 74. SUMMARY OF SWCB FUNDS EXPENDED FY 1976 - 1980

FY	1976	1977	1978	1979	1980	Total
Personnel	$22,757	$17,870	$14,899	$24,482	$18,101	$98,109
Fringe Benefits	5,234	4,110	3,427	5,630	4,164	22,565
Travel	2,302	1,680	1,687	1,539	1,021	8,229
Laboratory Analyses	8,813	6,251	4,552	5,955	2,452	28,023
Laboratory Equipment	5,007		73	25		5,105
Photo Supplies	142	57	51	95	16	361
Miscellaneous Supplies	154	6	3	517	3	683
Easement Recording	27					27
Bid Advertisement	194					194
Total	$44,630	$29,974	$24,692	$38,243	$25,757	$163,296

treated with sludge and has not had any maintenance since 1976. No breakdown of overall costs for the two sites has been attempted due to the extensive maintenance including various application rates of soil additives and small parcels of acreage reseeded each year. It should be realized that the major portion of the maintenance has been performed at the Sulphur Site. For details of reclamation costs, see the tables in Sections 6 and 7.

Due to the need for continued maintenance a request was made to EPA to extend the project for another two years until 1982. The request for extension was approved by EPA in October 1980. Under the terms of the extension the grant was converted to a cooperative agreement and the budget was amended to a 54:46 Federal to State ratio rather than a 60:40 ratio as in the original grant. The total grant amount was reduced from $225,158 to $210,070.

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GLOSSARY

Acidity - A measure of the extent to which a solution is acid. Usually measured by titrating with a base to a specific end point.

Acid Mine Drainage - Any acidic water draining or flowing on or from mines and affected by mining.

Alkalinity - A measure of the capacity to neutralize acids.

Benthic - Pertaining to organisms dwelling on the bottom of a body of water.

BOD - Biochemical oxygen demand which is a measure of the quantity of dissolved oxygen in milligrams per liter necessary for the decomposition of organic matter by micro-organisms.

Concentration - A weight:volume ratio used in water quality analyses commonly expressed in milligrams per liter (mg/l).

Diabase - A finely crystalline igneous rock.

Diatom - Any of a number of related microscopic algae.

Dike - A tabular body of igneous rock that cuts across the structures of surrounding rock.

Dip - The angle that a geologic formation makes with the horizontal.

Dissolved Oxygen - The amount of dissolved oxygen by weight present in water commonly expressed in milligrams per liter.

Efflorescent - Pertaining to the whitish crust formed on rocks by chemical alterations under arid conditions.

Facultative - Said of an organism capable of growth under a number of specific conditions.

Fauna - The entire animal population of a given area or environment.

Fecal Coliform - Bacteria normally found in the feces of warm-blooded animals commonly used as an indicator of fecal contamination of water supplies.

Gossan - An iron-bearing weathered product overlying a sulfide deposit.

Hardpan - A general term for a relatively hard impervious layer of soil occurring at a shallow depth formed by accumulation of mineral matter leached from the surface.

Heavy Metal - Any of the metals including copper, iron, lead, manganese and zinc with a specific gravity greater than 4, generally having several oxidation states, and readily forming complete ions.

Hydrograph - A graph showing stage, flow, or velocity of water with respect to time.

Igneous Rock - A rock formed by solidification of molten material.

Instantaneous Flow - The discharge of a stream at a particular instant of time expressed in cubic feet per second (cfs) or liters per second (l/s).

Load - The quantity of any given chemical constituent that a transporting stream carries during a given time period usually expressed in kilograms per day (Kg/d).

Macrobenthos - Bottom dwelling organisms visible to the unaided eye.

Metamorphic Rock - A rock formed by alteration of pre-existing rocks due to changes in temperature and pressure.

Nutrient - An element essential to plant growth including nitrogen, phosphorus, and potassium.

Pegmatite - A coarse-grained igneous rock usually formed in fissures and cracks in other igneous rocks.

Periphyton - Sessile biotal components of a fresh-water ecosystem.

pH - The negative logarithm of the hydrogen-ion activity which denotes the degree of acidity or of basicity of a solution.

Potash - The potassium content of a soil or fertilizer in terms of K_2O.

Precambrian - The earliest era of geologic time.

Pyrite - A common iron sulfide mineral principally used in the manufacture of sulfuric acid.

Reclamation - The procedures by which a disturbed area can be reworked to make it productive, useful, or aesthetically pleasing.

Schist - A metamorphic rock characterized by parallel layers of flaky minerals.

Sheet Erosion - The removal of a fairly uniform layer of soil material from the land surface by rainfall and runoff.

Specific Conductance - A measure of the ability of water to conduct an electric current giving an indication of the total dissolved solids content and commonly expressed in micromhos per centimeter at 25 degrees centigrade.

Strike - The direction that a geologic formation takes as it intersects the horizontal.

Substrate - The physical characteristics of the bottom of a stream channel.

Tailing - Wastes left from mining and milling processes.

Transect - An imaginary plane across a stream, normal to the flow direction.

Trellis Drainage - A drainage pattern characterized by parallel main streams with tributaries entering at or near right angles.

Turbidity - The state of opaqueness or reduced clarity of a fluid due to suspended matter.

Turnover - A period of uniform vertical temperature in lakes due to vertical convective circulation usually occurring in the spring and fall.

APPENDIX A

GENERALIZED DEED OF EASEMENT

THIS DEED OF EASEMENT, made by and between the property owner, party of the first part, and the Commonwealth of Virginia, State Water Control Board, party of the second part.

WITNESSETH:

WHEREAS, the party of the first part is the fee simple owner of the hereinafter described real estate, adjacent to and located on the waters of Contrary Creek in Mineral Magisterial District, Louisa County, Virginia;

WHEREAS, it has been represented to the party of the first part that the mining of minerals and the disposal of mineral waste on the said real estate in the vicinity of Contrary Creek by previous owners has resulted in severe water pollution problems, and has had an adverse affect on the natural and scenic quality of the subject real estate;

WHEREAS, the Commonwealth of Virginia, State Water Control Board, has determined that it would be in the public interest to reclaim mined areas and to remove the said mineral waste from the said real property, and to restore and preserve the natural and scenic qualities of the said real estate so as to abate the continued pollution of Contrary Creek and its related tributaries, and to restore the said Contrary Creek to its natural state;

WHEREAS, the Commonwealth of Virginia, State Water Control Board and the United States Environmental Protection Agency are in agreement concerning a project to demonstrate an approach to the elimination and/or control of acid and other mine related water pollution resulting from the abandoned mining operations such as those affecting the said real estate. The Commonwealth of Virginia, State Water Control Board, has determined that the said parcel of land possesses the necessary characteristics for inclusion in the said project;

WHEREAS, the party of the first part agrees to grant a right of way and easement over the said real estate to the party of the second part for the purpose of accomplishing the project, goals and objectives herein described.

NOW, THEREFORE, in consideration of the sum of One Dollar ($1.00), in hand paid, and other good and valuable considerations, the receipt of which is hereby acknowledged, and in further consideration of the mutual covenants and conditions hereinafter set forth, the party of the first part hereby grants and conveys unto the party of the second part for a period of five years from date a right of way and easement in the hereinafter described parcel of land, to reclaim mined areas and to remove mineral waste deposited on said land and to restore to their natural state those land areas and those portions of Contrary Creek and its tributaries affected by mining operations, to wit:

(Description of Parcel)

For the purpose of adequately determining the effectiveness of the herein described project, the party of the first part does hereby further grant and convey unto the party of the second part a right of way and easement to construct, operate and maintain for a period of five years from date a water monitoring station adjacent to and on the waters of Contrary Creek on the above described parcel of land.

The conditions and terms of the foregoing rights of way and easements are as follows:

a. In the performance of the herein described project, the party of the second part will confine its activities to that land area and those portions of Contrary Creek and its tributaries, affected by mining operations as of January 1, 1975.

b. In the exercise of its rights herein, the party of the second part, its successors and assigns, will utilize, preserve, protect and maintain the natural topography and terrain of the landscape of the said real estate.

c. For a period of five years from date, the party of the first part, its successors and assigns, upon reasonable notice, shall permit representatives of the party of the second part, and the United States Environmental Protection Agency to enter upon the said real estate at reasonable hours for the purpose of making periodic inspections of the reclaimed portions of the said property.

d. For a period of five years from date no activity will be conducted on said property that would in any way adversely affect the project, goals or objectives described herein.

e. Granting of this deed of easement shall not in any way limit the uses to which the property, other than the reclaimed area, may be placed by the party of the first part.

The party of the first part, its successors and assigns further grants unto the party of the second part the following rights and privileges:

(1) For a period of five years from date, the party of the second part, its successors and assigns or representatives may enter upon the said real estate at reasonable hours for the purpose of taking water samples from the above mentioned monitoring station.

(2) The party of the first part, its successors and assigns, further covenants and agrees that it will not make application to any governmental body for approval of a subdivision or resubdivision plan, a building or use permit, license, or zoning amendment which would in any way violate the restrictions hereinabove placed upon the said real estate for a period of five years from date.

This easement is contingent upon the following:

(1) The granting of funds for the project by the United States Environmental Protection Agency.

(2) The initiation of the project by the party of the second part.

APPENDIX B

ANALYTICAL PROCEDURES

WATER - DCLS

Acidity - manual NaOH titration to pH 8.3.

Alkalinity - titration by Fisher automatic titrator.

Suspended Solids - as per Standard Methods using Reeve Angel glass fiber filters.

Sulfate - turbidimetric.

BOD_5 - as per Standard Methods using YSI oxygen meter.

Copper, Iron, Manganese, Zinc - argon coupled plasma for simultaneous determination by emission spectroscopy (alternate approved test procedure for Virginia).

Lead - anodic stripping voltammetry (Virginia approved alternate test procedure).

Mercury - cold vapor atomic absorption.

Fecal Coliform - as per Standard Methods - membrane filter or multiple tube as requested and appropriate.

Turbidity - hach nephelometer.

SOIL

Titration Curve Method for Lime Requirement - DCLS

Samples were crushed and sieved through a 2 mm screen. All material greater than 2mm was discarded as rock. 10-gm samples of soil were placed into a series of 250-cc. Erlenmeyer flasks, and different amounts of 0.04 N $Ca(OH)_2$ were added, using 5 cc. as the equivalent of 1 ton of pulverized limestone per acre. Samples were then diluted to 100 cc. with distilled water. Suspensions were allowed to stand in the stoppered flasks for 4 days with thorough shaking twice a day. pH was determined with a glass electrode, and a titration curve was made by plotting pH values on the ordinate and tons of lime per acre on the abscissa. Lime requirements were determined by the amount $Ca(OH)_2$ required to reach pH of 6.5.

Water Extraction of Soluble Salts for Metals - DCLS

One hundred gm of dry soil or its equivalent of field moist soil is placed in 200 ml of distilled water in a 500-ml conical flask. The flask is stoppered and the suspension is shaken for a period of 2 hours or over night. The solution is filtered and the analysis made on the filtrate. The concentration in the 1:2 extract, multiplied by 2 is the concentration in the soil.

pH and Nutrient Availability - SCS

pH - Determined on a 1:1 soil to water solution on a volume basis by glass electrode.

Nutrient Availability - According to double dilute acid test method as prescribed in "Laboratory Procedures, "Soil Testing Laboratory, VPI&SU Extension, MA-143, 1979.

SLUDGE - DCLS

Alkalinity, Fluoride, Chloride - diluted 1:10 with water, filtered and run by standard methods.

Alkalinity - Titration
Chloride - Titration
Fluoride - Specific ion electrode

Ammonia - distillation from MgO plus titration.

Metals (except lead and mercury) - acid digestion plus atomic absorption.

Lead and Mercury - see method for water above.

Total Nitrogen - Robertson method. Digested with H_2SO_4, $FeSO_4$, $CuSO_4$, and Na_2SO_4 plus distillation and titration.

METALS UPTAKE IN VEGETATION - HITTMAN ASSOCIATES, INC.

Grass samples were washed with distilled, deionized water and oven dried at 80°C for 15-18 hours. After cooling, the samples were ground to the best possible mixture, divided into two portions and weighed. One portion was subjected to dry ashing (for all elements except arsenic, phosphorus, mercury and selenium) and the other portion was subjected to wet ashing for analyses of these elements. An additional portion was analyzed for boron after treatment with saturated calcium hydroxide followed by ashing.

Most metal analyses were performed by atomic absorption on a Perkin-Elmer Model 603. Iron, zinc and manganese were present in the solutions in the ppm range and flame photometry was used to atomize the sample. The rest of the elements were present in the ppb range and a graphite furnace (Perkin-Elmer HGA 2100) was used to atomize the sample. Mercury was analyzed by the cold vapor technique. Boron was determined colormetrically.

APPENDIX C

METRIC CONVERSION

To Convert	To	Multiply By
Centimeters	Inches	3.937×10^{-1}
Cubic meters	Cubic yards	1.308
Hectares	Acres	2.471
Kilograms	Pounds	2.205
Kilograms/hectare	Pounds/acre	8.921×10^{-1}
Kilometers	Miles (statute)	6.214×10^{-1}
Liters	Gallons	2.642×10^{-1}
Liters/second	Cu ft/second	3.531×10^{-2}
Meters	Feet	3.281
Tonnes (metric)	Tons (short)	1.102
Tonnes/hectare	Tons/acre	4.494×10^{-1}

Appendix D

MAJOR SOURCES OF ACID AND HEAVY METALS WHICH CONTRIBUTE TO THE ACID MINE WATERS OF CONTRARY CREEK, LOUISA COUNTY, VIRGINIA

FINAL REPORT

June 1, 1977 to May 30, 1979

Sponsored by a grant from the

VIRGINIA STATE WATER CONTROL BOARD
MINE DRAINAGE ABATEMENT PROJECT

in cooperation with the

ENVIRONMENTAL PROTECTION AGENCY

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TABLE OF CONTENTS

Page

Summary 211

Introduction 212

Study Site 213

Efflorescent Sulfate Minerals Associated with Acid Mine Drainage 216

Site Identification Codes 227

Diurnal Variation in Contrary Creek during Dry Weather . . 228

Specific Conductance and pH Transect of Contrary Creek . . . 235

The Acid Seep Pools of the Sulfur Mine 243

Variation in Water Chemistry during Rainstorms 246

Discussion 271

Acknowledgements 273

Presentations and Related Publications 274

References 275

Tables

1. Secondary Sulfate Minerals Occurring as Efflorescences 217

2. Secondary Sulfate Minerals Found at the Allah Cooper Mine 219

3. Secondary Sulfate Minerals Found at the Cofer Mine . . 220

4. Rainstorm of July 2, 1978 and Diurnal Study of June 30 - July 1, 1978 229

5. pH and Specific Conductance Transect of Contrary Creek and Tributaries at the Sulfur Site 236

6. Chemical Data for Acid Seep Pools 244

7. Rainstorm of June 8, 1978 (CC-4) 247

8. Rainstorm of June 19, 1978 (CC-4) 248

9. Rainstorms of June 20 and 21, 1978 (CC-4) 250

Page
10. Rainstorm of September 12, 1978 (CC-3) 252

11. Rainstorm of September 12, 1978 (CC-4) 254

12. Chemical Data for Contrary Creek and Tributaries, December 8, 1978 267

13. Metal Loads for Contrary Creek and Tributaries, December 8, 1978 268

Figures

1. Location of Sulfate Minerals at the Sulfur Mine . . . 226

2. Midstream pH and Specific Conductance Transect 239

3. Specific Conductance vs. Time (June 19, 1978). 256

4. pH Conductance vs. Time (June 19, 1978) 256

5. Discharge Conductance vs. Time (June 19, 1978) 256

6. Zn, Fe and Al Conductance vs. Time (June 18, 1978) . . 257

7. Cu and Mn Conductance vs. Time (June 18, 1978) 257

8. Zn, Fe and Al Loads vs. Time (June 18, 1978) 258

9. Cu and Mn Loads vs. Time (June 18, 1978) 258

SUMMARY

A two-year study of a watershed affected by acid mine drainage was undertaken to identify the specific sources of acid and heavy metal concentrations entering the main stream and to examine the variations in water chemistry during a rainstorm. The study site was Contrary Creek located in Louisa County, Virginia, near the town of Mineral. The results of this study are summarized below:

1. Sources of acid and heavy metals are of three types: a) mine effluents, b) acid seeps from the base of tailings piles and c) soluble hydrated sulfate minerals occurring in the top soil or on ore surfaces.
2. Only two effluents are identified as issuing from mine entrances (shafts) and both contribute only small proportions of the total acid and metal loads.
3. Acid seeps from the base of tailings piles contribute the major portion of acid and heavy metals during dry periods between storm events.
4. Acid and heavy metals are stored as soluble sulfate minerals in the top layer of mine tailings during dry periods. During storm events the major portion of pollutants is derived from the dissolution and rapid flushing out of these sulfates. The longer the dry period, the greater the increase in metal concentrations when the next rainstorm hits.
5. These sulfate minerals commonly occur as efflorescent coatings on ore surfaces and mine tailings and the most abundant are melanterite ($FeSO_4 \cdot 7H_2O$), rozenite ($FeSO_4 \cdot 4H_2O$), and copiapite ($FeFe_4(SO_4)_6(OH)_2 \cdot 20H_2O$) followed by the halotrichite-pickingerite series and gypsum.

6. pH/conductivity transects have shown where major increases in dissolved solids occur and have located sources of acid seepage where additional reclamation may be needed.

INTRODUCTION

Mobilization of toxic metals and acid by weathering of sulfide tailings has caused considerable degradation of water quality in the Contrary Creek watershed located near the town of Mineral in Louisa County, Virginia. These tailings were produced by active mining of massive sulfide ores occurring as lenses in quartz-sericite and chlorite schists. Mining began around 1834 when gossan was removed for iron ore. Later, gold, silver, copper, lead and zinc minerals were mined periodically. The pyrite was mined for sulfur until 1922 when active mining ceased. Three mines are located along Contrary Creek: the Arminius, the Boyd Smith and the Sulfur Mines, and large deposits of mine tailings are found along the creek banks adjacent to each mine.

In 1974, Miorin, Klingensmith and Saliunas completed a feasibility study on Contrary Creek in which it was proposed that erosion and leaching of acid mine waters could be greatly reduced by reclamation of the tailings piles. Reclamation began under a cooperative agreement between the Environmental Protection Agency and the Virginia State Water Control Board for two of the three tailings sites: the Boyd Smith and the Sulfur sites. The third site, the Arminius Mine, is owned and maintained by New Jersey Zinc and Callahan Mining Companies. Reclamation of Arminius also took place under the direction of Chandler Mortimer, an environmental consultant for Callahan and New Jersey Zinc.

The present study was sponsored by the E.P.A. and the S.W.C.B. under the Contrary Creek Mine Drainage Abatement Project. This study was originally directed toward answering the following questions:

1) What and where are the specific sources of major metal contamination in Contrary Creek?

2) How do the pH and metal concentrations vary during a rainstorm? What factors cause these variations?

3) How are the heavy metals partitioned between the dissolved and particulate phases? Are there substantial changes in the partitioning during a rainstorm?

STUDY SITE

The Contary Creek watershed is located at about 38°2'30"N and 77°54'W near the town of Mineral in Louisa County, Virginia. It drains about a 7 square mile area and empties into Lake Anna, one of the most popular recreational lakes in the state. Three mine sites are located along Contrary Creek: the Sulfur site, the Boyd Smith site, and the Arminius site (going from downstream up). Detailed descriptions can be found in the feasibility study by Miorin, Klingensmith and Saliunas (1974). Acid mine waters seep from each site into Contrary Creek from extensive mine tailings located at the edge of the creek. The largest quantity of sulfide tailings are found at the Sulfur site below which the water quality is the poorest.

EFFLORESCENT SULFATE MINERALS ASSOCIATED WITH ACID MINE DRAINAGE

An extensive survey of efflorescent sulfate mineralogy was completed in the Contrary Creek watershed. About 20 distinct mineral species have been identified and these are listed, along with their chemical compositions (from Fleischer, 1975), solubilities and appearances in Table 1. Additional sulfate minerals were identified from the nearby Allah Cooper Mine, north of the Sulfur Mine and the Cofer Mine, east of the Contrary Creek watershed. These minerals are given in Tables 2 and 3, and they are provided as a comparison to those in Table 1. The minerals from Table 1 are indicative of an acidic aqueous environment wheras those from Table 3 are indicative of a more neutral aqueous environment. The minerals from Table 2 indicate a high lead in the source material and, in fact, Luttrell (1966) mentions that the ore from Allah Cooper is dominantly sphalerite and galena with a high silver content.

X-ray diffractometry by the powder method has been used to identify these minerals. Many of the minor mineral species are intimately mixed with the more abundant minerals; thus identification has been both tedious and time consuming. Careful attention has been given to the physical appearance, mode of occurrence and associated minerals in order to facilitate field identification of mineral hand specimens in the future. A brief description of each mineral is given below.

Melanterite occurs as light greenish-blue, vitreous, botryoidal to granular crusts on massive sulfide boulders and on stream sediments associated with acid seeps at the base of the mine dumps. It dehydrates to rozenite during dry weather and is usually associated with it. This dehydration is reversible if the humidity rises sufficiently, thus melanterite is one of the most common minerals at the Sulfur Mine during damp periods. It should be

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TABLE 1. SECONDARY SULFATE MINERALS OCCURRING AS EFFLORESCENCES

NAME	FORMULA	SOLUBILITY	DESCRIPTION
Common Minerals:			
#Melanterite	$FeSO_4 \cdot 7H_2O$	Soluble	Vitreous, greenish-blue to white, translucent grains
#Rozenite	$FeSO_4 \cdot 4H_2O$	Slowly soluble	White to tan earthy crusts
#Copiapite	$FeFe_4(SO_4)_6(OH)_2 \cdot 20H_2O$	Very soluble	Bright yellow to brownish, pearly to waxy luster, clayey texture
Magnesiocopiapite	$MgFe_4(SO_4)_6(OH)_2 \cdot 20H_2O$	Very soluble	Bright yellow to brownish, pearly to waxy luster, clayey texture
Aluminocopiapite	$Al_{.67}Fe_4(SO_4)_6(OH)_2 \cdot 20H_2O$	Very soluble	Bright yellow to brownish, pearly to waxy luster, clayey texture
Ferricopiapite	$Fe_{.67}FE_4(SO_4)_6(OH)_2 \cdot 20H_2O$	Very soluble	Bright yellow to brownish, pearly to waxy luster, clayey texture
Halotrichite	$FeAl_2(SO_4)_4 \cdot 22H_2O$	Soluble	Silky white radially fibrous spheres
Pickeringite	$MgAl_2(SO_4)_4 \cdot 22H_2O$	Soluble	Silky white radially fibrous spheres
Gypsum	$CaSO_4 \cdot 2H_2O$	Slightly soluble	White to grey, earthy to vitreous, transparent to opaque, in grains bladed crystals, and asbestiform fibers
Uncommon Minerals:			
#Ferrohexahydrite	$FeSO_4 \cdot 6H_2O$	Soluble	White sugary botryoidal crusts
#Siderotil	$FeSO_4 \cdot 5H_2O$	Soluble	Light blue, white or yellowish, granular or botryoidal masses
Szomolnokite	$FeSO_4 \cdot H_2O$	Soluble	White earthy crusts

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TABLE 1 (Continued)

NAME	FORMULA	SOLUBILITY	DESCRIPTION
Jarosite	$KFe_3(SO_4)_2(OH)_6$	Insoluble	Orange-yellow resinous grains
Chalcanthite	$CuSO_4 \cdot 5H_2O$	Very soluble	Vitreous turquoise blue translucent grains
Alunogen	$Al_2(SO_4)_3 \cdot 18H_2O$	Very soluble	White subvitreous grains
Scarce Minerals:			
Rhomboclase	$HFe(SO_4)_2 \cdot 4H_2O$	Slowly soluble	Pearly white subtranslucent platelets, clayey texture
Fibroferrite	$Fe(OH)(SO_4) \cdot 5H_2O$	Soluble	Silky white matted or radiating fibers
Coquimbite	$Fe_2(SO_4)_3 \cdot 9H_2O$	Very soluble	Earthy to vitreous, white to pale lavender grains
Paracoquimbite	$Fe_2(SO_4)_3 \cdot 9H_2O$	Very soluble	Vitreous pale lavender grains
Antlerite	$Cu_3SO_4(OH)_4$	Insoluble @	Vitreous emerald green to dark green crusts and grains
*Brochantite	$Cu_4SO_4(OH)_6$	Insoluble @	Drusy yellow-green to dark green earthy crusts

- found previously by Mitchell (1977) and/or Katz (1961) as well as during present study.

* - not found during this study, noted by Katz (1961).

@ - readily soluble in acid.

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TABLE 2. Secondary Sulfate Minerals found at the Allah Cooper Mine

Name	Formula	Solubility	Description
Brochantite	$Cu_4SO_4(OH)_6$	Insoluble, @	emerald green, translucent to opaque, vitreous to earthy
Linarite	$PbCuSO_4(OH)_2$	Insoluble, @	dark azure blue, translucent to opaque, vitreous to earthy
Anglesite	$PbSO_4$	Insoluble, @	colorless to white, transparent to opaque, adamantine to earthy
Leadhillite ?	$Pb_4SO_4(CO_3)_2(OH)_2$	Insoluble, @	colorless to white, transparent to opaque, adamantine to earthy

@ - readily soluble in acid

TABLE 3. Secondary Minerals found at the Cofer Mine - Prospect

Name	Formula	Solubility	Description
Antlerite	$Cu_3SO_4(OH)_4$	Insoluble, @	dark green, earthy to vitreous, opaque to translucent
Brochantite	$Cu_4SO_4(OH)_6$	Insoluble, @	green to greenish-blue, earthy to vitreous, opaque to translucent
Chalcanthite	$CuSO_4 \cdot 5H_2O$	Very Soluble	turquoise blue, earthy to vitreous, opaque to translucent
Gypsum	$CaSO_4 \cdot 2H_2O$	Slightly Soluble, @	white to gray, earthy to vitreous, transparent to opaque
Linarite	$PbCuSO_4(OH)_2$	Insoluble, @	dark azure blue, earthy to vitreous, transparent to opaque
Malachite	$Cu_2CO_3(OH)_2$	Insoluble, @	emerald green, botryoidal to powdery, waxy to earthy, opaque
Serpierite	$Ca(Cu,Zn)_4(SO_4)_2(OH)_6 \cdot 3H_2O$	Insoluble, @	blue-green, earthy, opaque

@ - readily soluble in acid

noted that melanterite and the following four minerals contain the divalent ferrous ion. The reduced state of iron suggests that these minerals are slow to oxidize further to ferric iron even though they are exposed to the atmosphere. The reduced state of iron also suggests that these minerals are sufficiently short lived to preclude extensive oxidation. These observations agree well with the fact that the ferrous sulfates tend to occur in unsheltered locations where they are stable only during dry periods, from the time of their crystallization until the next rain. Melanterite frequently has trace metals substituting for iron in its structure, e.g. up to 7.2% Zinc, 15.0% Copper and 1.9% Manganese (Palache *et al.*, 1951, p. 501) and can be an important source of heavy metals during a rainstorm.

Ferrohexahydrite occurs as white, sugary, botryoidal crusts on waste rock at the base of mine tailing piles. One would expect to find ferrohexahydrite commonly as an intermediate phase in the dehydration of melanterite to rozenite; however, this mineral has only been found infrequently and without melanterite and rozenite. The six-water form is apparently stable only under a very restricted range of environmental conditions or when it incorporates trace metal impurities into its structure.

Siderotil is found in light blue to yellowish to white, granular and botryoidal masses on rocks and wood associated with acid seeps at the base of the mine dumps. Siderotil is also a logical intermediate mineral phase in the formation of rozenite from melanterite. Nevertheless, it is not found with melanterite and the only occurrence with rozenite shows no signs of dehydrating to the four-water salt. Jambor and Traill (1963) determined that siderotil could crystallize directly from solution and that it is only stable if at least 5% of the iron is replaced by copper. They found siderotil with as much as 11.2% copper. Therefore the presence of siderotil suggests significant trace metal substitution at the Sulfur Mine.

Rozenite is probably the most commonly encountered mineral on the dumps of the Sulfur Mine. It occurs as white to tan, earthy coatings on massive sulfides and on creek sediments at the base of the dumps. Rozenite is especially notable when it forms a snow white powder on the dark brown limonitic weathering rinds of massive sulfide boulders. It is frequently mixed with melanterite on the sediments at the base of the mine dumps.

Unlike the other ferrous sulfates, szomolnokite tends to be found with the ferric sulfates, copiapite and rhomboclase, and with gypsum. It appears as a white earthy crust intimately mixed with these minerals. It seems to be found in sheltered places with the ferric species where it can exist long enough to form by dehydration, or it is found on rocks exposed to full sunlight where dehydration can be accelerated by heating of the rock.

Rhomboclase is found as pearly white subtranslucent platelets with a clayey texture enrusting copiapite. Szomolnokite has also been found with rhomboclase. Rhomboclase and the next four minerals are ferric sulfates and usually occur in sheltered locations where the mineral efflorescences have remained exposed to the atmosphere long enough for ferrous iron salts to oxidize to the ferric state, i.e. beneath protruding mine timbers, beneath rocks and under overhanging banks.

Fibroferrite occurs as silky white aggregates of matted fibers and as radiating fibers on copiapite. The matted fibrous texture is diagnostic in hand specimens. It is found only scarcely and in sheltered locations.

Coquimbite and paracoquimbite are found as fine crusts on copiapite. The small pale lavender to white grains have a vitreous luster. Because of their small quantities and scarce occurrence it is difficult to isolate from copiapite.

Copiapite is one of the more common minerals at the Sulfur Mine and it is frequently mistaken for native sulfur. Uncombined sulfur may occur at the mine but it would be found in inaccessible subsurface reducing environments and not exposed to the atmosphere in evaporative zones like copiapite. Copiapite is important not only as a major secondary mineral in the deposit but also as a substrate for many of the scarce minerals with which it is associated, i.e. rhomboclase, fibroferrite, paracoquimbite and szomolnokite. Copiapite is bright sulfur yellow to brownish yellow with a pearly to waxy luster. It is composed of microscopic transparent plates which occur in botryoidal to shapeless masses. Some earlier researchers at the deposit suggested a chemical relationship between copiapite and old wood. However, it appears that copiapite and wood occur together frequently because the wood provides the necessary mechanical shelter. Copiapite may contain up to 2.0% Zn, 4.6% Cu (Palache *et al.*, 1951, p. 625) and perhaps other toxic metals due to isomorphous substitution of various metal cations for iron. Thus, since it readily dissolves when a blowing rain flushes its sheltered sites, trace metals can be released. Chemical analysis on many samples of copiapite from the Sulfur Mine is currently in progress to determine the degree of trace metal substitution. Copper has been detected in all copiapite samples tested.

Jarosite is found as orange-yellow resinous grains associated with copiapite and gypsum. It occurs only sparingly at the mine and it is intimately mixed with other minerals. Thus it is difficult to isolate and analyze. This difficulty is most unfortunate since jarosite belongs to a large isomorphous series of minerals and would be expected to contain various metals substituting for potassium and iron. However, jarosite is the most insoluble sulfate mineral found and would not contribute a significant amount of heavy metals to Contrary Creek during a rainstorm. Jarosite is sometimes confused with the yellow ocher variety of goethite. However, where jarosite does occur with goethite at the Sulfur Mine, the goethite is a distinctive brown.

Halotrichite and pickeringite are found as silky white, radially fibrous spheres frequently associated with alunogen and occasionally with chalcanthite. The minerals are commonly found as an efflorescent crust on fine grained sediments in the creek bed, also as well developed crystals under overhanging rocks. These two minerals are treated together since they belong to a group of minerals chemically and structurally very similar. Minerals of this group contain as much as 3.0% Zn and 6.8% Mn (Palache et al., 1951, p. 522-529). Pickeringite may not be a valid species from this locality. The bulk chemical analyses underway at present should reveal the degree of isomorphism and chemical substitution.

Chalcanthite is found as turquoise blue vitreous grains on quartz pebbles in the creek and on mine timbers. It is associated with pickeringite, alunogen, copiapite and siderotil.

Antlerite occurs as vitreous, emerald-green to forest-green grains on fine grained mine spoils adjacent to the creek. It has only been found at one location on the mine dumps, but here it is plentiful and mixed with gypsum. This mineral is quite insoluble. The same mineral crusts have remained essentially unchanged through many months of exposure to rain.

Brochantite has not been found at the Sulfur Mine during this study. However, Katz (1961) found brochantite as drusy yellow-green to dark-green earthy crusts, but only in minute quantity. In surveying the secondary minerals at the nearby Cofer mine, the author has found abundant brochantite.

Alunogen is seen as white subvitreous grains generally associated with halotrichite-pickeringite and sometimes with chalcanthite. Usually it is found forming on fine grained sediments in the creek bed. Alunogen, as well as halotrichite and pickeringite contain aluminum and are an indication of the dissolution of soils, sediments or bedrock by subsurface acid water.

Gypsum is very common at the Sulfur Mine, occurring in many different forms. With antlerite it is a grey-white earthy mass. With copiapite and jarosite it develops vitreous, transparent, radiating, bladed crystals. Gypsum also is found as white granular to asbestiform masses with szomolnokite. Gypsum is frequently seen as a ring on quartz pebbles partially immersed in Contrary Creek. The calcium sulfate precipitates at the air water interface on pebbles. Gypsum is probably the most common efflorescent sulfate in acid mine water environments.

Figure 1 shows the locations of sulfate minerals at the Sulfur site on the map drawn by Katz (1961). Some of the features mapped by Katz have been altered somewhat by the recent reclamation efforts.

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Key To Representative Mineral Locations:

M - melanterite, rozenite
C = copiapite
H = halotrichite-pickeringite, alunogen
R = rhomboclase, fibroferrite, paracoquimbite
J = jarosite
A = antlerite
G = gypsum
Ch = chalcanthite
F = ferrohexahydrite, siderotil
S = szomolnokite

EXPLANATION

1. Northern-Most Shaft (Vertical)
2. Exploration Pit
3. Vertical Shafts
4. Tailings
5. Storage Bins
6. Probable Mill Site
7. Lake
8. Main Dump
9. Main Buildings
10. Tipple
11. Main Shaft (Vertical)
12. Ore Shoot
13. Probable Cable Hoist
14. Old Gossan Pits
15. Old Gossan Pits
16. Southern-Most Shaft
17. Loading Shoot

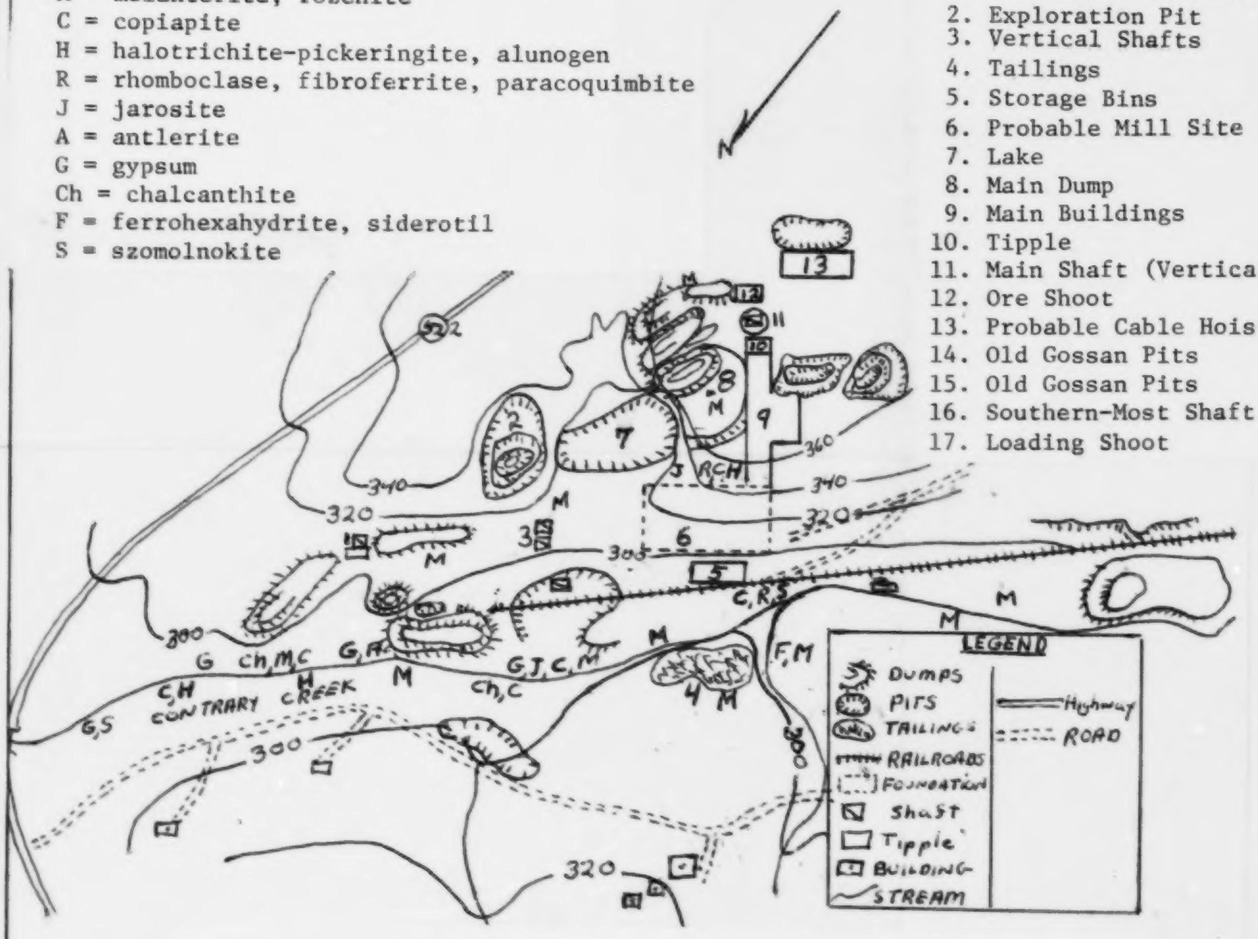


FIGURE 1. LOCATION OF SULFATE MINERALS AT THE SULFUR MINE SITE

SITE IDENTIFICATION CODES

Contrary Creek	SWCB No.	Site Description
CC-1	MS-1	A few meters upstream from Arminius Mine (gauge site)
CC-2	MS-2	Several meters downstream from Arminius Mine (gauge site)
CC-3	MS-3	Just below Boyd Smith Mine at bridge crossing (gauge site)
CC-4	MS-4	Downstream a few meters from 522 bridge (gauge site)
Tributaries		
Tr-1	Tr-1	Tributary on west side of Contrary draining south bank of tailings pile
Tr-2	Tr-2	Shaft drainage located between between green pond and Contrary Creek on east side of creek
Tr-4	Tr-4	Tributary above shaft drainage from Boyd Smith Mine
Tr-6	Tr-6	Shaft drainage at Boyd Smith Mine
Tr-7	Tr-7	2-3 meters below confluence of Tr-4 and Tr-6
Tr-8	Tr-8	Main drainage from Boyd Smith Mine a few meters from confluence with Contrary Creek
Tr-9	Tr-9	Diversion ditch upstream from Tr-8
Tr-10	Tr-10	Diversion ditch downstream from Tr-8

DIURNAL VARIATION IN CONTRARY CREEK DURING DRY WEATHER

On June 30 and July 1, 1978, a study was undertaken to determine if the abrupt changes observed during a rainstorm are superimposed upon any regular daily variation in the baseline chemistry and discharge of Contrary Creek. The data (see Table 4) demonstrate that a very slight variation occurs with a twenty-four hour periodicity.

A. Variations in Discharge

The daily discharge peaks around noon and falls to a minimum about midnight at monitoring station #4. The difference between maximum and minimum flows for a given day is on the order of ten percent which is within the error range for a single discharge measurement. However, this difference is significant because continuous monitoring reveals a relative difference in gauge height which indicates a real change of flow. On the gauge height recorder the diurnal discharge fluctuation has been observed for almost every dry day during the summer of 1978. The daily peaks and troughs are themselves superimposed upon a gradual long term flow decrease. As groundwater seeping into the creek slowly decreases, the average daily discharge as well as the maximums and minimums gradually fall during the dry spell after a storm. Of course, the average daily discharge never quite reaches a steady value before another rainstorm comes along and raises the water table. Preliminary investigation of gauge height recordings for the late autumn and winter show a general absence of the peak and trough effect. However, the gradual, dry weather decrease of average daily flow in response to the falling water table still occurs during cold periods. This seasonal absence of the diurnal peak and trough effect suggests that a warm weather mechanism is responsible for the cyclical flow variation. Evaporation directly from the creek and/or

TABLE 4 - The Rainstorm of July 2, 1978 and Diurnal Variation Study
June 30 to July 1, 1978, Station #4, Contrary Creek

Date and Time	pH	Specific Conductance (µmhos/cm)	Gauge Height (ft)	Discharge (cfs)	Metal Concentrations (mg/ℓ) Cu	Zn	Fe	Al	Mn	Metal Loads (mg/s) Cu	Zn	Fe	Al	Mn
June 30, 1978														
3:05 pm	3.00	-	.870	1.97	1.36	6.67	-	-	2.65	75.9	372	-	-	148
4:05	2.98	-	.865	1.86	1.32	6.70	-	-	2.60	69.5	353	-	-	137
5:05	2.97	-	.865	1.86	1.33	6.86	-	-	2.62	70.1	361	-	-	138
5:35	2.96	-	.865	1.86	1.31	6.84	-	-	2.47	69.0	360	-	-	130
6:05	2.95	-	.865	1.86	1.42	6.97	-	-	2.70	74.8	367	-	-	142
7:05	2.95	-	.860	1.74	1.51	7.07	-	-	2.67	74.4	348	-	-	132
8:05	2.98	-	.860	1.74	1.42	7.05	-	-	2.64	70.0	347	-	-	130
9:05	2.97	-	.860	1.74	1.55	7.24	-	-	2.70	76.4	357	-	-	133
10:05	2.97	-	.860	1.74	1.55	7.09	-	-	2.58	76.4	349	-	-	127
11:05	2.97	-	.860	1.74	1.46	7.16	-	-	2.61	71.9	353	-	-	129
12:05	2.97	-	.860	1.74	1.50	6.97	-	-	2.61	73.9	343	-	-	129
July 1, 1978														
1:05 am	2.96	-	.860	1.74	1.50	6.80	-	-	2.61	73.9	335	-	-	129
2:05	2.97	-	.860	1.74	1.48	6.82	-	-	2.55	72.9	336	-	-	126
3:05	2.97	-	.860	1.74	1.49	6.82	-	-	2.53	73.4	336	-	-	125
4:05	2.99	-	.860	1.74	1.45	6.84	-	-	2.55	71.5	337	-	-	126
5:05	3.00	-	.860	1.74	1.47	6.72	-	-	2.50	72.4	331	-	-	123
6:05	3.00	-	.860	1.74	1.39	6.77	-	-	2.55	68.5	334	-	-	126
7:05	3.00	-	.865	1.86	1.38	6.75	-	-	2.45	72.7	356	-	-	129
8:05	3.01	-	.865	1.86	1.40	6.65	-	-	2.60	73.7	350	-	-	137
9:05	3.01	-	.865	1.86	1.40	6.75	-	-	2.46	73.7	356	-	-	130
10:05	3.01	-	.865	1.86	1.36	6.43	-	-	2.52	71.6	339	-	-	133
11:05	3.01	-	.870	1.97	1.31	6.55	-	-	2.55	73.1	365	-	-	142
12:05	3.00	-	.870	1.97	1.36	6.25	-	-	2.50	75.9	349	-	-	139
1:05 pm	3.00	-	.865	1.86	1.28	6.45	-	-	2.51	67.4	340	-	-	132
2:05	2.98	-	.865	1.86	1.36	6.21	-	-	[illegible]	[illegible]	[illegible]			

TABLE 4 - (continued)

Date and Time	pH	Specific Conductance (μmhos/cm)	Gauge Height (ft)	Discharge (cfs)	Metal Concentrations (mg/ℓ)					Metal Loads (mg/s)				
					Cu	Zn	Fe	Al	Mn	Cu	Zn	Fe	Al	Mn
3:05	2.95	-	.860	1.74	1.45	6.55	-	-	2.71	71.5	323	-	-	134
4:05	2.96	-	.860	1.74	1.45	6.77	-	-	2.70	71.5	334	-	-	133
5:05	2.96	-	.855	1.63	1.47	6.99	-	-	2.65	67.9	323	-	-	122
6:06	2.94	-	.850	1.51	1.50	7.01	-	-	2.67	64.1	300	-	-	114
7:00	2.96	-	.850	1.51	1.46	7.20	-	-	2.61	62.4	308	-	-	112
8:00	2.96	-	.845	1.41	1.54	7.26	-	-	2.84	61.5	290	-	-	113
9:00	2.94	-	.845	1.41	1.61	7.14	-	-	2.82	64.3	285	-	-	113
10:00	2.95	-	.845	1.41	1.61	7.14	-	-	2.70	64.3	285	-	-	108
11:00	2.96	-	.845	1.41	1.61	7.18	-	-	2.72	64.3	287	-	-	109
12:00	2.97	-	.845	1.41	1.58	7.09	-	-	2.82	63.1	283	-	-	113
July 2, 1978														
1:00 am	2.99	-	.845	1.41	1.59	7.16	-	-	2.78	63.5	286	-	-	111
2:00	3.00	-	.845	1.41	1.57	7.07	-	-	2.80	62.7	282	-	-	112
3:00	2.99	-	.845	1.41	1.62	7.09	-	-	2.73	64.7	283	-	-	109
4:00	2.98	-	.850	1.51	1.60	6.95	-	-	2.69	68.4	297	-	-	115
5:00	2.94	-	.860	1.74	1.94	7.50	-	-	2.76	95.6	370	-	-	136
6:00	2.89	-	.900	2.70	2.33	7.98	-	-	2.70	178	610	-	-	206
7:00	2.84	-	.915	3.10	3.44	11.4	-	-	2.88	302	1000	-	-	253
8:00	2.97	-	.940	3.80	2.03	10.6	-	-	2.71	218	1140	-	-	292
9:00	2.99	-	.955	4.22	1.90	8.80	-	-	2.40	227	1050	-	-	287
10:00	3.09	-	.955	4.22	1.29	7.48	-	-	2.38	154	894	-	-	284
11:00	3.17	-	.960	4.35	1.21	6.53	-	-	2.55	149	804	-	-	314
12:00	3.20	-	.960	4.35	1.10	5.88	-	-	2.32	136	724	-	-	286
1:00 pm	3.23	-	.960	4.35	0.94	5.50	-	-	2.39	116	678	-	-	294
2:00	3.24	-	.955	4.22	0.93	5.66	-	-	2.41	111	676	-	-	288
3:00	3.24	-	.950	4.09	0.91	6.00	-	-	2.40	105	695	-	-	298

TABLE 4 - (continued)

Date and Time	pH	Specific Conductance (μmhos/cm)	Gauge Height (ft)	Discharge (cfs)	Metal Concentrations (mg/ℓ)					Metal Loads (mg/s)				
					Cu	Zn	Fe	Al	Mn	Cu	Zn	Fe	Al	Mn
4:00	3.24	-	.950	4.09	0.81	7.30	-	-	2.38	93.8	846	-	-	276
5:00	3.23	-	.945	3.95	0.95	10.2	-	-	2.54	106	1140	-	-	284
6:00	3.23	-	.940	3.80	0.96	10.4	-	-	2.46	103	1120	-	-	265
7:00	3.21	-	.935	3.66	1.03	9.47	-	-	2.29	107	982	-	-	237
8:00	3.20	-	.935	3.66	0.96	8.30	-	-	2.09	99.5	860	-	-	217
9:00	3.20	-	.930	3.51	1.10	7.18	-	-	2.27	109	714	-	-	226
10:00	3.20	-	.930	3.51	0.97	6.53	-	-	2.15	96.4	649	-	-	214
11:30	3.22	-	,925	3.38	0.99	5.88	-	-	2.10	94.8	563	-	-	201

Rain began at 4:30 am, July 2, 1978, a moderate rainstorm with 0.64 inches of rain recorded in Louisa.
The last rain fell on June 22, a moderate thundershower with 0.84 inches of rain recorded in Louisa.
The creek discharge was approaching base flow by July 2.

transpiration losses from the water table close to the creek may account for the variations in flow.

B. Variations in Water Chemistry

Copper and zinc concentrations fluctuate approximately ten percent in association with the daily discharge oscillations. The metal concentrations peak about twelve hours out of phase with discharge, that is metal concentrations reach their maximum when discharge reaches a minimum. This effect is harder to observe for manganese because the scatter in the analytical data obscures the actual variation. Iron and specific conductance were not tested in these samples because the oxidation and hydrolysis of iron had proceeded too far. The pH was measured but its validity is marginal because of interferences from iron hydrolysis. The pH values do show a slight rise and fall in phase with the discharge variation, but these are less than the uncertainty of the measurement.

The copper, zinc and manganese loads do not show the diurnal peaks and troughs but are constant throughout a daily cycle because the fluctuations in metal concentrations offset the variations in discharge, i.e., the concentrations peak when discharge reaches a minimum and vice versa. The constancy of the metal loads demonstrates that soluble metals flow from the creek at a steady rate during any given dry period. Therefore, the regular daily concentration oscillations must be due to the cyclical variations in the flow which is available to dilute the mine drainage. Metal loads do gradually decrease over extended periods of dry weather. This load decline would be expected due to the slow decrease of base flow and mine seepage which respond to the falling water table.

Evaporation and transpiration are both plausible mechanisms for varying the flow of Contrary Creek. From the upper end of the Arminius to monitoring station #4, a distance of almost 4 km, the entire creek bed is exposed to direct sunlight because the poor quality of the creek water inhibits the growth of overhanging vegetation. This direct exposure accelerates the daily heating of Contrary Creek and allows greater wind velocities over the water. Both the heating and the wind encourage evaporation. The shallowness of the creek, less than a foot in most places, permits faster heating and produces a higher surface to volume ratio, both of which enhance evaporation. It is well known that plant transpiration prevents significant amounts of water from reaching the water table. However, it is not clear whether daily transpirational removal of water from the water table near the creek can produce noticeable diurnal fluctuations of groundwater flow into the creek. If so, transpiration induced variations in groundwater flow are thought to be greater above the Arminius Mine in the upper end of the Contrary Creek basin. Here the trees and underbrush grow right to the water's edge. Both of these mechanisms, evaporation and transpiration, function with a twenty-four hour periodicity in their intensity and could therefore produce a cyclic removal of water but not heavy metals from the creek. This phenomenon would result in the daily concentration maximums.

The constant arrival time of discharge peaks and troughs at monitoring station #4 permits an evaluation of the plausibility of the aforementioned mechanisms. Transpiration peaks around midday and evaporation rates are highest about mid-afternoon. The discharge reaches a minimum about midnight. This schedule implies that the water parcel which passes monitoring station #4 at midnight has been subaerial for at least ten to twelve hours. During dry weather this is not an unreasonable travel time for water coming from the upper reaches of the Contrary Creek basin.

Preliminary inspection of gauge height recordings at monitoring station #3 indicates that the peaks and troughs arrive there about three hours earlier than at station #4. The variation in flow is small at station #3 also. The differences in arrival times suggests that the peaks move downstream as a minute wave with a twenty-four hour period.

Further study would be necessary to describe thoroughly the origin of the peak and trough effect, e.g., better knowledge of: creek velocities at more points, the discharges of the many minor tributaries joining Contrary Creek, and the variation in peak amplitudes in relation to ambient conditions. Of course, additional research along these lines is beyond the scope of this project. Fortunately, these diurnal variations are small and integrated with the conspicuous changes during a rainstorm they are insignificant. Furthermore, the mechanisms which produce the diurnal changes may not be operating during the cloudy humid weather accompanying a rainstorm. A complete cycle of diurnal chemical variation was monitored only once, but the daily chemical oscillations are presumed to occur throughout the summer and early fall whenever the gauge height recorder shows diurnal flow variations. The baseline chemical data prior to storm of 6-19-78 record a small fragment of the daily cycle on another occasion. During a protracted dry spell, the acid seeps dry up and metal loads decrease. This trend is only evident on a time scale of several weeks and is no more important than the weak diurnal fluctuations when describing the rapidly changing creek chemistry in a rainstorm.

SPECIFIC CONDUCTANCE AND pH TRANSECT OF CONTRARY CREEK

A transect of specific conductance and pH data has been collected at 50 m intervals along an 1100 m section of Contrary Creek flowing through the Sulfur Mine site. The samples were gathered on September 26, 1978 when the creek was at fairly low flow. At each 50 m interval pH, specific conductance and temperature were determined at midstream and a point close to each bank. These three point transects were continued upstream until the creek became so narrow at 850 m that only one point was necessary to characterize the stream. Very little Sulfur Mine waste was heaped above this point and there was very little cross sectional variation. Samples were also collected at midstream on three tributaries entering Contrary Creek.

The pH and specific conductance data reveal several interesting trends in the creek chemistry. The specific conductance offers a crude yet useful measure of the dissolved solids in a given volume of water. The specific conductance of Contrary Creek nearly triples while passing through the Sulfur Mine site (see Table 5). Along this 1 km stretch three tributaries and numerous seeps swell the creek's discharge. An almost tripled dissolved solids concentration and a substantially augmented discharge produce a more than tripled dissolved solids load. All of the increased dissolved load can be attributed to the Sulfur Mine seepage because the tributaries have very clean water. The pH falls one and a half units along the transect. This means a thirty-two fold increase in hydronium ion, or acid, concentration.

Graphical analysis of the longitudinal transect of creek chemistry can facilitate finding areas of high and low acid drainage. The slope of the specific conductance versus distance in Figure 2 represents the rate of change in dissolved solids concentration along the creek. When the slope is horizontal as from 1000 to 850 m, there is zero change in dissolved solids concentration.

TABLE 5 - pH and Specific Conductance Transect of Contrary Creek and Tributaries at the Sulfur Mine Site, September 26, 1978

Location	pH			Specific Conductance (µmhos/cm)			Station Description
	Northwest side	Midstream	Southeast side	Northwest side	Midstream	Southeast side	
Monitoring Station #4	3.36	3.34	3.36	975	995	1000	Just downstream from the bridge and a bend in the creek, well mixed.
Rt. 522 Bridge (0 meters)	3.41	3.37	3.25	832	1032	1083	Under downstream edge of bridge, 21 meters below fresh creek entering from NW.
50 meters (upstream of bridge)	3.25	3.27	3.27	980	976	968	2 meters above old bridge abutments, massive sulfide exposed on SE bank.
100 meters	3.28	3.30	3.29	981	973	978	Pyritiferous sediment on both banks, steep rock face on SE bank.
150 meters	3.32	3.32	3.31	946	960	979	Small waste rock pile on SE bank.
200 meters	3.37	3.37	3.22	907	923	1485	Acid seeps entering from SE bank, large waste rock pile on SE bank.
250 meters	3.47	3.47	3.30	858	855	1031	Large waste rock pile and a few mine timbers on SE bank.
300 meters	3.44	3.51	3.37	917	829	912	Large waste rock pile on SE bank, some pyritiferous waste on NW bank.
350 meters	3.22	3.62	3.37	1476	730	811	Very large tailings of pile on NW bank, numerous acid seeps entering.
400 meters	3.68	3.72	3.64	643	636	670	Very large tailings pile on NW bank, some pyritiferous waste on SE bank.
450 meters	3.77	3.96	3.76	615	466	519	10 meters downstream from small dam and water fall, very large tailings pile on NW bank.

TABLE 5 - (continued)

Location	pH Northwest side	pH Midstream	pH Southeast side	Specific Conductance (μmhos/cm) Northwest side	Specific Conductance (μmhos/cm) Midstream	Specific Conductance (μmhos/cm) Southeast side	Station Description
500 meters	3.95	3.98	3.51	499	468	681	Braided stream channel, acid seep pools on SE bank.
550 meters	4.01	4.09	4.04	467	458	462	Braided stream channel, pyritiferous sediments on both banks.
600 meters	4.17	4.19	4.03	436	452	499	Braided stream channel, broad bottomland covered with waste rock on SE bank.
650 meters	4.39	4.37	4.37	381	393	498	Braided stream channel, broad bottomland covered with waste rock on SE bank.
700 meters	4.76	4.73	4.40	352	353	368	Broad bottomland covered with waste rock on SE bank.
750 meters	4.78	4.76	4.76	351	354	354	Some waste rock on SE bank and floodplain.
800 meters	4.79	4.80	4.74	309	314	319	Fairly wide floodplain, only a little waste from the sulfur mine upstream of this point.
850 meters	5.02	-	4.49	320	-	392	Creek becomes marrower, 5 meters downstream from a fresh creek entering from NW.
900 meters	-	4.75	-	-	365	-	Broad bare floodplain on SE bank.
950 meters	-	4.80	-	-	369	-	Broad bare floodplain on SE bank.
1000 meters	-	4.82	-	-	364	-	Floodplain still broad, but no longer bare.
Fresh tributary at 21 meters	–	6.86	-	-	36	–	Entering from NW, very clean water (analysed).

TABLE 5 - (continued)

Location	pH			Specific Conductance (μmhos/cm)			Station Description
	Northwest side	Midstream	Southeast side	Northwest side	Midstream	Southeast side	
TR-1, tributary at 463 meters	-	5.97	-	-	161	-	Entering from NW, just before confluence with Contrary Creek.
TR-1	-	6.56	-	-	113	-	55 meters upstream of confluence with Contrary Creek, flowing past tailings pile.
TR-1	-	6.62	-	-	96	-	130 meters upstream of confluence with Contrary Creek, above all the tailings.
Fresh tributary at 855 meters	-	6.70	-	-	29	-	Entering from NW.

The last rain was a light shower on September 22 with 0.22 inches recorded in Louisa. Otherwise, the last half of September was fairly dry, therefore the creek was approaching base flow.

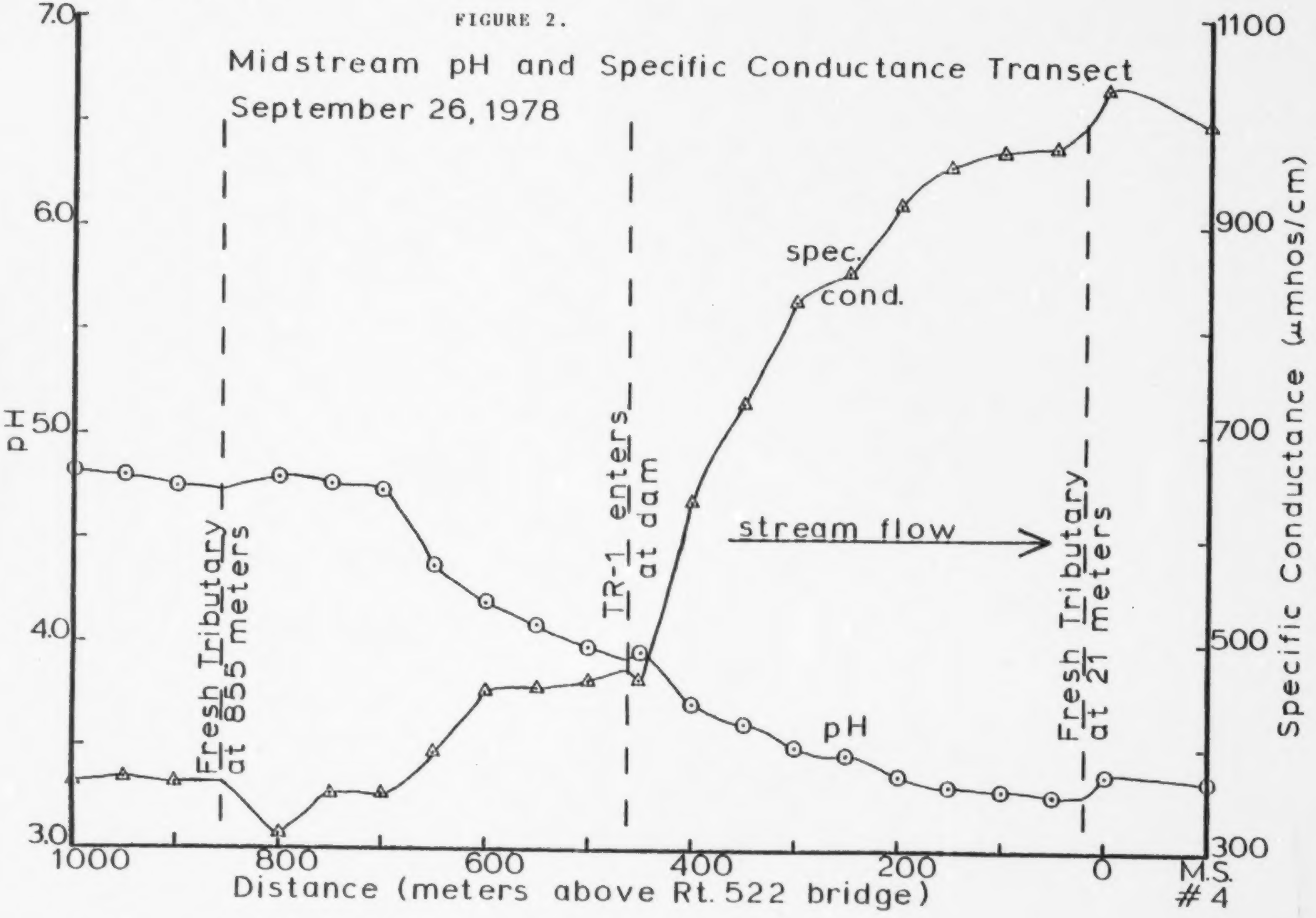


FIGURE 2.

Midstream pH and Specific Conductance Transect
September 26, 1978

The very steep slope from 450 to 150 m indicates a very rapid increase in dissolved solids and marks the location of heaviest acid seepage. The specific conductance versus distance curve rises gently between 800 and 450 m. The modest slope reflects the beginning of moderate mine drainage. The slope of the pH versus distance graph falls very slowly between 1000 and 700 m indicating a very slight addition of acid. Perhaps part of this gradual pH drop especially above 850 m is due to the oxidation and hydrolysis of iron already in the creek from the Boyd Smith and Arminius Mines. The pH values fall much more rapidly between 700 and 50 m. In this range the slope remains fairly constant, suggesting a constant influx of acid between these points. This trend conflicts with the evidence from specific conductance which indicates much heavier seepage below 450 m and lighter seepage above. However, it must be remembered that pH units are a negative logarithmic scale of hydronium ion (H_3O^+) concentration. Therefore a constant negative slope for pH values represents a positive logarithmic increase in acid seepage. On a typical logarithmic curve the last half, which is the distance below 430 m, has the steepest slope, which is analogous to the highest acid discharge. Between 1000 and 450 m the hydronium ion concentration (assumed = activity) rises from 0.15×10^{-4} to 1.10×10^{-4} moles/liter. Between 45 and 50 m the hydronium ion concentration goes from 1.10×10^{-4} to 5.37×10^{-4} moles/liter. Thus about 80% of the acid concentration originates between 450 and 50 m, the region between the large tailings pile and old bridge abutments. If discharge measurements were available and acid loads were computed, more than 80% of the acid load could be shown to originate between 450 and 50 m.

The cross sectional variation in pH and specific conductance also shows the location of acid seeps (Table 6). As an example, at 650 m the specific conductance falls from 498 μmhos/cm near the southeast bank to 303 at midstream to 381 near the northwest bank. These values indicate acid seepage from the southeast which is not unexpected since waste rock is piled on the southeast bank. The pH gradient is not as obvious. A more extreme gradient is found at 350 m where the specific conductance varies from 1476 μmhos/cm on the northwest side of the creek to 730 at midstream to 811 near the southeast bank. Heavy acid seepage from the northwest bank where the largest tailings are located and modest acid seepage from the southeast where there are smaller accumulations of mine waste produce this cross sectional gradient. The pH values vary sympathetically being lowest where seepage is highest. These conductivity and pH gradients are convenient tracers for indicating where greater reclamation effort would be efficacious.

Whenever a fresh tributary enters Contrary Creek, the resulting dilution usually causes a kink in the smooth trends of the pH and specific conductance curves as seen in Figure 2. Generally, the tributary water hugs the bank from which it entered and gradually mixes over the next 50 m. The first sample interval below a tributary usually reflect this dilution in the sample taken next to the bank and to a lesser extent at midstream. This cross sectional gradient mimics those gradients due to seepage on the opposite bank. Monitoring station #4 is about 100 m downstream of a fresh tributary. There was some concern that the creek might not be well mixed at this station. However, the data in Table 5 and data collected numerous other times have shown the creek to be homogeneous at station #4. The right angle bend, the shallow depth and the turbulence in the creek thoroughly mix the water above this station. Therefore, one sample taken at midstream will be characteristic of the entire creek and can be used for accurately calculating metal loads.

The tributary entering Contrary Creek at 460 m, known as Tr-1, flows along the southern edge of the main tailings pile for 120 m and suffers measurable degradation in this short distance. Tr-1 is still much cleaner than Contrary Creek. A small man-made waterfall just below the confluence of Tr-1 causes a rapid mixing of the creek and tributary. Accordingly samples taken at 450 m do not have a wedge of fresh water along the northwest bank. In fact, the sample taken on the northwest side shows evidence of acid seepage.

THE ACID SEEP POOLS OF THE SULFUR MINE

All three mines along Contrary Creek trickle acid and metal laden water into the creek. At the Boyd Smith and Arminius Mines, these seeps generally enter from above the creek water level. The Sulfur Mine also has a few seeps entering the creek above the water level. The paucity of these seeps in relation to the huge input of dissolved solids and acid revealed by the pH and specific conductance transect suggests a much larger hidden flow of metal and acid. This flow of mine seepage is obscured because it enters Contrary Creek below the water level. The only manifestations of this subsqueous seepage are the dark brown pools which cluster along the creek banks and in shallow depressions of the creek bed. The pools are most numerous at the base of the huge mine tailings pile which borders 130 m of the creek beginning 330 m above the Rt. 522 bridge. However, pools can be found at many scattered locations from the bridge to the area 750 m upstream.

The seep pools are a good indication of the chemistry of the groundwater flowing through the tailings piles at the Sulfur site. Ten seep pools have been analyzed and the results are shown in Table 6. The pH values are all close to 2.0 and they have very high dissolved solids as reflected in the specific conductance which ranges from 20,000 - 30,000 micromhos and is more than 20 times the values found in Contrary Creek. When water of this composition is found flowing from a mine portal, a cementation plant would be set up to recover the copper. These seeps have about the highest concentration of copper ever reported for acid mine water. Unfortunately, the discharge is not nearly enough to warrant a cementation operation.

The seep pools develop their maximum size during dry weather. However, if the dry period is long enough, like the drought in the summer of 1977, then

Table 6. Chemical Data for Acid Seeps
Collected in Summer, 1978*

Seep	Date	Cu	Zn	Fe	Mn	Cd	Pb	Ca	Mg	Na	K	pH	spec. cond.
220 SE	7-01-78	4.75	14.6	365	6.4	0.05	<0.5	88	126	5.0	3.3	2.71	3,150
335 NW	7-01-78	411	563	9130	60	2.40	<0.5	300	1520	3.2	0.3	2.11	19,300
338 NW	9-22-78	144	534	7750	95	0.95	<0.5	480	2280	6.7	0.7	2.28	19,900
343 NW	9-22-78	59.4	825	12500	168	0.65	<0.5	580	3900	10.0	0.3	2.37	27,300
359 NW	9-22-78	741	619	15200	59	2.65	<0.5	510	1570	3.5	0.1	2.37	26,100
370 NW	7-01-78	187	387	9730	66	0.70	<0.5	260	1450	6.7	0.8	2.22	20,600
430 NW	6-12-78	516	400	16200	54	1.50	<0.5	560	1600	3.7	0.1	2.0	23,400
430 NW	6-23-78	623	389	13800	32	1.72	<0.5	290	1210	2.3	<0.1	2.0	23,500
430 NW	7-01-78	756	528	15600	66	3.25	<0.5	250	1410	3.5	0.2	2.0	25,300
430 NW	9-22-78	692	497	14300	57	2.40	<0.5	510	1830	2.4	<0.1	2.25	23,400

* concentration in mg/l

the seep pools are found to dwindle in size. The maximum development during modest dry spells suggests that the pools are flushed away during the high discharge in wet weather. This agrees well with field observations. During dry weather the seep pools cannot engage in turbulent mixing with the creek because the creek velocities are too low and the pools are too dense. Of course there is a small exchange of ions by Brownian motion, but this is miniscule compared to the exchange resulting from turbulent mixing. This situation compares well to the density imposed layering in estuaries where a lens of fresh river water rides out across of abody of denser salt water. When the river floods, it flushes much of the underlying body of salt water from the estuary. The response in Contrary Creek is analogous. As the creek's discharge rises, its velocity increases and the shear forces exerted on the creek bed grown. These augmented shear forces result in greater turbulence and the entrainment of the dense seep pools. Once the creek subsides the pools begin to grow again. The density of the 430 m pool is very consistent. On three occasions during dry weather the values ranged from 1.064 to 1.067 g/cc. The one time the density dropped below 1.06 g/cc is June 23, 1978, two days after a series of three thundershowers. On this day the discharge was still above normal. This low density probably reflects the dilution of the pool by mixing.

One final note should serve to illustrate how the acid seep pools resist mixing. When the creek bed is disturbed upstream of a seep pool, the ferric hydroxide precipitate which carpets the bottom sends an orange cloud drifting downstream. As this cloud passes above the seep pool, gravitational settling of the suspended particles drops them upon the seep-creek water interface. Rather than cross this interface, the bright orange particles highlighted against the dark brown pool glide on downstream. The ferric hydroxide follows the current which refuses to mix with the acid pool.

VARIATION IN WATER CHEMISTRY DURING RAINSTORMS

Several attempts were made to collect simultaneous discharge and water chemistry data at eight tributary sites and four sites in Contrary Creek at regular intervals during a rainstorm. Unfortunately, this sampling effort was never achieved because of the highly unpredictable nature of the weather during the period of research. Nevertheless, several sets of samples were collected with automatic samplers at two of the downstream sites in Contrary Creek during six different rainstorms. These data along with the results of investigations on efflorescent metal sulfate minerals and transects on stream water quality in Contrary Creek are presented. Further interpretation of the data is being prepared in the M.S. thesis of Tom Dagenhart.

For six thunderstorms between June 8 and September 12, 1978, the creek water was collected at regular intervals for a few hours before and on through the rainstorm. The data are provided in Tables 4, 7-11 and Figures 3-9. samples were collected with an ISCO automatic sampler, packed with ice to slow the oxidation of iron. The first storm, June 8, was sampled at one and a quarter hour intervals for a day. The second storm, June 19, was sampled at one hour intervals for one day. Then the sampler was reset to collect at three hour intervals for four days. During this period two additional storms were monitored on June 20 and 21. The fifth storm, July 2, was sampled at one hour intervals for most of a day. Water samples for the first five storms were only collected at monitoring station #4. The sixth storm, September 12, was sampled every half hour for twelve hours at both monitoring stations #3 and #4. Then sampling was continued for another day and a half at longer intervals. For this last storm pre-rainstorm baseline samples were not collected and the first sample was not taken until one hour into the storm. The baseline and early rainstorm samples were missed becaused of the extreme difficulty of forecasting the weather.

TABLE 7 - The Rainstorm of June 8, 1978, Station #4, Contrary Creek

Date and Time	pH	Specific Conductance (µmhos/cm)	Gauge Height (ft)	Discharge (cfs)	Metal Concentrations (mg/ℓ)					Metal Loads (mg/s)				
					Cu	Zn	Fe	Al	Mn	Cu	Zn	Fe	Al	Mn
June 8, 1978														
10:30 am	3.60	525	.970	4.65	.83	5.15	24.5	6.5	-	109	678	3230	856	-
11:00	3.62	525	.970	4.65	.81	5.05	26.0	6.5	-	107	665	3420	856	-
11:30	3.62	525	.965	4.50	.82	4.86	26.3	6.3	-	105	619	3350	803	-
12:00	3.62	530	.965	4.50	.82	4.79	26.5	6.0	-	105	610	3380	765	-
12:30	3.60	540	.965	4.81	.81	4.54	24.7	5.8	-	110	618	3360	790	-
1:00 pm	3.42	670	.980	4.96	1.26	5.15	35.0	7.5	-	177	723	4920	1050	-
2:15	3.40	680	.995	5.45	1.42	6.63	37.5	8.2	-	219	1020	5790	1270	-
3:30	3.58	530	1.000	5.6	.94	4.94	25.5	5.6	-	149	783	4040	888	-
4:45	3.70	483	1.000	5.6	.78	4.34	22.2	4.8	-	124	688	3520	761	-
6:00	3.74	469	1.000	5.6	.78	4.21	21.3	4.4	-	124	668	3380	698	-
7:15	3.77	466	1.000	5.6	.76	4.08	21.5	4.4	-	121	647	3410	698	-
8:30	3.75	471	1.000	5.6	.71	4.68	23.5	4.8	-	113	742	3730	761	-
9:45	3.72	502	1.000	5.6	.83	6.72	25.5	5.1	-	132	1070	4040	809	-
11:00	3.73	483	.995	5.45	.80	5.48	25.5	4.8	-	123	846	3940	741	-
June 9, 1978														
12:15	3.74	476	.995	5.45	.81	4.74	26.8	5.6	-	125	732	4140	864	-
1:30 am	3.77	461	.990	5.29	.76	4.40	26.3	4.8	-	114	659	3940	719	-
2:45	3.81	442	.985	5.13	.75	4.11	26.0	5.1	-	109	597	3780	741	-
4:00	3.81	445	.985	5.13	.74	4.11	27.1	5.1	-	108	597	3940	741	-
5:15	3.81	448	.980	4.96	.74	4.20	27.8	5.3	-	104	590	3900	744	-
6:30	3.83	450	.975	4.81	.76	4.30	28.0	5.6	-	104	586	3810	763	-
7:45	3.82	457	.975	4.81	.76	4.37	28.5	6.0	-	104	595	3880	817	-
9:00	3.82	461	.970	4.65	.76	4.51	29.0	5.3	-	100	594	3820	698	-
10:15	3.80	466	.970	4.65	.76	4.55	29.3	4.8	-	100	599	3860	632	-
12:45	3.62	509	.960	4.35	.74	4.34	28.3	4.6	-	91	535	3490	567	-

Rain began at 12:15, a light thunder shower with 0.31 inches of rain recorded in Louisa.
On the previous day there had been a light thunder shower with 0.11 inches of rain recorded in Louisa.
The creek had not yet returned to base flow.

TABLE 8 - The Rainstorm of June 19, 1978, Station 4, Contrary Creek

Date and Time	pH	Specific Conductance (μmhos/cm)	Gauge Height (ft)	Discharge (cfs)	Metal Concentrations (mg/ℓ)					Metal Loads (mg/s)				
					Cu	Zn	Fe	Al	Mn	Cu	Zn	Fe	Al	Mn
June 19, 1978														
1:00 pm	3.28	835	.865	1.86	1.26	6.1	47.3	10.5	2.57	66.4	321	2490	553	135
3:00	3.25	864	.860	1.74	1.31	6.4	50.2	11.5	2.64	64.6	315	2470	567	130
5:00	3.26	874	.855	1.63	1.39	6.1	51.7	9.5	2.63	64.2	282	2390	439	121
6:15	3.10	1025	.970	4.65	2.03	6.8	56.5	19.0	2.50	267	896	7440	2500	329
6:30	-	-	1.070	8.4	-	-	-	-	-	-	-	-	-	-
7:15	2.95	1561	1.060	8.0	7.56	24.0	110	35.0	2.74	1710	5440	24900	7930	621
7:50	-	-	1.055	7.8	-	-	-	-	-	-	-	-	-	-
8:15	3.28	783	1.100	9.6	2.28	12.2	36.0	13.0	2.15	620	3320	9790	3530	585
8:30	-	-	1.130	10.9	-	-	-	-	-	-	-	-	-	-
9:15	3.42	567	1.135	11.2	1.36	5.8	18.7	9.5	1.76	431	1840	5930	3010	558
10:15	3.52	529	1.140	11.4	1.19	5.1	19.7	8.3	1.77	384	1650	6360	2680	571
11:15	3.66	417	1.145	11.6	.81	3.6	14.5	6.0	1.35	266	1180	4760	1970	443
12:15	3.80	366	1.145	11.6	.62	4.0	13.0	4.8	1.41	204	1310	4270	1580	463
June 20, 1978														
1:15 am	3.88	437	1.125	10.7	.78	10.1	13.0	4.8	1.80	236	3060	3940	1450	545
2:15	3.89	422	1.100	9.6	.70	7.3	13.0	2.5	1.91	190	1980	3530	680	519
3:15	3.89	384	1.080	8.8	.65	5.6	14.0	3.6	1.48	162	1400	3490	897	369
4:15	3.89	365	1.060	8.0	.53	4.6	13.5	3.6	1.40	120	1040	3060	816	317
5:15	3.88	358	1.045	7.4	.50	3.3	16.1	6.0	1.35	105	692	3370	1260	283
6:15	3.87	364	1.030	6.8	.52	3.1	17.6	6.0	1.29	100	597	3390	1160	248
7:15	3.88	373	1.015	6.2	.55	2.9	18.7	4.8	1.36	96.6	509	3280	843	239
8:15	3.88	378	1.005	5.8	.58	2.9	19.2	4.8	1.43	95.3	476	3150	788	235
9:15	3.87	400	.995	5.45	.60	3.1	20.7	4.8	1.50	92.6	478	3190	741	232
10:15	3.85	406	.990	5.29	.62	3.2	23.7	7.1	1.49	92.9	479	3550	1060	223
11:15	3.82	416	.980	4.96	.64	3.2	23.1	7.1	1.56	89.9	449	3240	997	219
12:15	3.79	427	.975	4.81	.68	3.4	23.7	8.3	1.61	92.6	463	3230	1130	219

TABLE 8 - (continued)

Date and Time	pH	Specific Conductance (µmhos/cm)	Gauge Height (ft)	Discharge (cfs)	Metal Concentrations (mg/ℓ)					Metal Loads (mg/s)				
					Cu	Zn	Fe	Al	Mn	Cu	Zn	Fe	Al	Mn
1:15 pm	3.75	445	.970	4.65	.67	3.3	25.0	7.1	1.59	88.2	435	3290	935	209
2:15	3.71	456	.960	4.35	.70	3.3	25.0	9.5	1.75	86.2	407	3080	1170	216
3:15	3.67	477	.955	4.22	.70	3.6	25.5	9.5	1.75	83.7	430	3050	1140	209
4:15	3.63	488	.950	4.09	.70	3.6	25.0	8.3	1.75	81.1	417	2900	961	203
5:15	3.61	487	.945	3.95	.74	3.8	27.1	7.1	1.74	82.8	425	3030	794	195

Rain began at 5:45 pm, a heavy thundershower with 3.01 inches of rain recorded in Louisa.
The last rain fell on June 13, a light rainstorm with 0.27 inches of rain recorded in Louisa.
The creek discharge was approaching base flow by June 19.

TABLE 9 - The Rainstorms of June 20 and 21, 1978, Station #4, Contrary Creek

Date and Time	pH	Specific Conductance (µmhos/cm)	Gauge Height (ft)	Discharge (cfs)	Metal Concentrations (mg/ℓ)					Metal Loads (mg/s)				
					Cu	Zn	Fe	Al	Mn	Cu	Zn	Fe	Al	Mn
June 20, 1978														
4:15 pm	3.63	488	.950	4.09	.70	3.60	25.0	8.3	1.75	81.1	417	2900	961	203
5:15	3.61	487	.945	3.95	.74	3.80	27.1	7.1	1.74	82.2	425	3030	794	195
6:00	3.47	603	.940	3.80	.79	4.05	10.3	-	1.80	85.0	436	1110	-	194
6:35	-	-	1.100	9.6	-	-	-	-	-	-	-	-	-	-
7:15	3.22	900	1.100	9.6	4.07	17.8	40.0	19.0	1.76	1110	4840	10870	-	478
8:25	3.65	427	1.090	9.2	-	-	-	-	-	-	-	-	-	-
9:00	3.51	461	1.080	8.8	.70	3.50	6.0	-	1.38	174	872	1500	-	344
12:00	3.57	432	1.030	6.8	.58	2.80	8.3	-	1.20	112	539	1600	-	231
June 21, 1978														
3:00 am	3.53	476	.990	5.29	.66	3.20	9.9	-	1.30	98.9	479	1480	-	195
6:00	3.51	549	.970	4.65	.84	5.30	13.0	-	1.54	111	698	1710	-	203
9:00	3.49	587	.960	4.35	.81	4.45	14.1	-	1.61	99.8	548	1740	-	198
12:00	3.48	596	.955	4.22	.91	4.52	20.2	-	1.69	109	540	2410	-	202
3:00 pm	3.48	606	.945	3.95	.85	4.48	15.6	-	1.75	95.1	501	1750	-	196
6:00	3.38	625	.935	3.66	.84	4.52	14.6	-	1.78	87.1	469	1510	-	184
6:40	-	-	1.225	15.7	-	-	-	-	-	-	-	-	-	-
7:15	-	-	1.210	14.8	-	-	-	-	-	-	-	-	-	-
8:10	-	-	1.365	25.1	-	-	-	-	-	-	-	-	-	-
9:00	3.68	323	1.340	22.7	.54	2.58	1.8	-	1.09	347	1660	1160	-	701
12:00	3.79	361	1.210	14.8	.53	4.41	3.1	-	1.18	222	1848	1300	-	495
June 22, 1978														
3:00 am	3.77	362	1.115	10.2	.49	2.63	5.1	-	1.08	142	760	1470	-	312

TABLE 9 - (continued)

Date and Time	pH	Specific Conductance (µmhos/cm)	Gauge Height (ft)	Discharge (cfs)	Metal Concentrations (mg/ℓ)					Metal Loads (mg/s)				
					Cu	Zn	Fe	Al	Mn	Cu	Zn	Fe	Al	Mn
6:00	3.72	406	1.070	8.4	.55	2.76	5.9	-	1.24	131	657	1400	-	295
9:00	3.71	435	1.035	7.0	.64	3.01	9.6	-	1.35	127	597	1900	-	268
12:00	3.77	462	1.020	6.4	.68	3.28	11.9	-	1.36	123	594	2160	-	246
3:00 pm	3.69	484	1.000	5.6	.71	3.39	13.6	-	1.40	113	538	2160	-	222
6:00	3.60	549	.975	4.81	.80	3.70	13.1	-	1.50	109	504	1780	-	204
9:00	3.59	531	.965	4.50	.83	3.88	21.9	-	1.54	106	494	2790	-	196
12:00	3.59	571	.955	4.22	.88	3.93	20.5	-	1.60	105	470	2450	-	191
June 23, 1978														
3:00 am	3.59	570	.950	4.09	.91	4.30	24.6	-	1.69	105	498	2850	-	196
6:00	3.59	581	.950	4.09	.91	4.61	26.1	-	1.72	105	534	3020	-	199
9:00	3.59	564	.945	3.95	.97	4.48	29.6	-	1.72	109	501	3310	-	192
12:00	3.58	563	.935	3.66	.94	4.58	31.4	-	1.74	97.4	475	3250	-	180

Rain began at 6:15 pm on June 20, a moderate thundershower with 0.34 inches of rain recorded in Louisa.
Rain began at 6:00 pm on June 21, a moderate thundershower with 0.39 inches of rain recorded in Louisa.
The last rain fell on June 19, a heavy thundershower with 3.01 inches of rain recorded in Louisa.
The storms of the 20th and 21th were monitored accidentally while checking the recovery response of Contrary Creek after the storm of 19th.

Table 10. The Rainstorm of September 12, 1978, Station #3, Contrary Creek

					Concentrations(mg/l)									
Date and Time	pH	Specific Conductance (µmhos/cm)	Gauge Height (ft)	Discharge (l/s)	Cu	Zn	Fe	Mn	Cd	Pb	Ca	Mg	Na	K
Sept. 12, 1978														
7:00 pm	-	-	0.580	12.7	-	-	-	-	-	-	-	-	-	-
10:00	-	-	0.575	11.6	-	-	-	-	-	-	-	-	-	-
10:30	-	-	0.700	59.5	-	-	-	-	-	-	-	-	-	-
10:50	-	-	0.735	77.3	-	-	-	-	-	-	-	-	-	-
11:10	-	-	0.715	66.8	-	-	-	-	-	-	-	-	-	-
11:25	3.79	476	0.770	97.4	1.50	4.98	2.55	2.36	0.035	<0.1	26.8	15.7	2.76	2.42
Sept. 13, 1978														
12:05 am	4.40	304	0.930	232.2	0.51	3.37	.90	1.50	0.015	<0.1	20.1	11.9	2.95	2.25
12:25	4.60	287	1.060	413.4	0.37	3.80	.62	1.35	0.015	<0.1	19.6	11.6	2.92	2.33
12:30	4.76	248	1.070	433.2	0.26	3.24	.64	1.16	0.010	<0.1	16.9	10.0	2.83	2.15
12:55	4.53	442	1.090	475.7	1.64	26.8	2.38	3.09	0.090	<0.1	46.7	23.6	2.50	3.20
1:25	4.27	638	1.215	750.4	0.89	20.2	1.38	2.55	0.065	<0.1	27.2	17.2	2.51	2.32
1:55	4.79	311	1.150	597.5	0.48	8.71	1.52	1.79	0.030	<0.1	22.8	10.5	2.52	1.99
2:25	5.64	171	1.085	464.4	0.07	2.40	0.46	1.16	0.010	<0.1	12.3	6.4	2.53	1.63
2:55	6.01	138	1.020	334.1	0.04	1.44	0.32	1.03	0.010	<0.1	10.5	5.8	2.47	1.63
3:25	6.14	137	0.955	257.7	0.04	1.31	0.16	1.11	0.010	<0.1	10.0	5.8	2.45	1.61
3:55	6.15	139	0.925	229.4	0.04	1.25	.42	1.18	0.010	<0.1	10.2	6.0	2.45	1.60
4:25	6.10	146	0.905	209.5	0.05	1.29	.67	1.16	0.010	<0.1	10.4	6.1	2.49	1.60
4:55	6.02	148	0.880	186.9	0.05	1.36	.24	1.15	0.010	<0.1	10.6	6.3	2.55	1.57
5:25	6.03	148	0.855	165.7	0.04	1.37	.53	1.11	0.010	<0.1	10.7	6.5	2.59	1.58
5:55	6.03	154	0.840	152.9	0.04	1.41	.13	1.06	0.010	<0.1	10.8	6.6	2.62	1.60
6:25	5.93	156	0.820	135.9	0.04	1.40	.21	1.07	0.010	<0.1	11.1	6.8	2.63	1.53
6:55	5.89	161	0.805	123.2	0.04	1.46	.72	1.13	0.010	<0.1	11.5	7.0	2.66	1.56
7:25	5.79	167	0.790	109.9	0.05	1.52	.22	1.11	0.010	<0.1	11.7	7.3	2.69	1.58
7:55	5.68	171	0.775	100.5	0.05	1.59	.13	1.12	0.010	<0.1	12.4	7.6	2.70	1.65
8:25	5.56	184	0.760	91.2	0.06	1.65	.30	1.17	0.010	<0.1	13.0	8.1	2.70	1.84
8:55	5.61	185	0.750	85.5	0.06	1.62	.21	1.19	0.010	<0.1	12.7	7.8	2.72	2.31
9:25	5.51	185	0.745	82.7	0.07	1.67	.13	1.18	0.010	<0.1	13.4	8.2	2.69	1.65
9:55	5.49	189	0.735	77.3	0.07	1.69	.36	1.19	0.010	<0.1	13.7	8.4	2.74	1.63
0:25	5.45	194	0.725	71.9	0.07	1.78	.21	1.18	0.010	<0.1	14.2	8.8	2.72	1.64
0:55	5.43	197	0.720	69.4	0.08	1.82	.21	1.20	0.010	<0.1	14.3	8.8	27.3	1.65

Table 10. The Rainstorm of September 12, 1978, Station #3, Contrary Creek (continued)

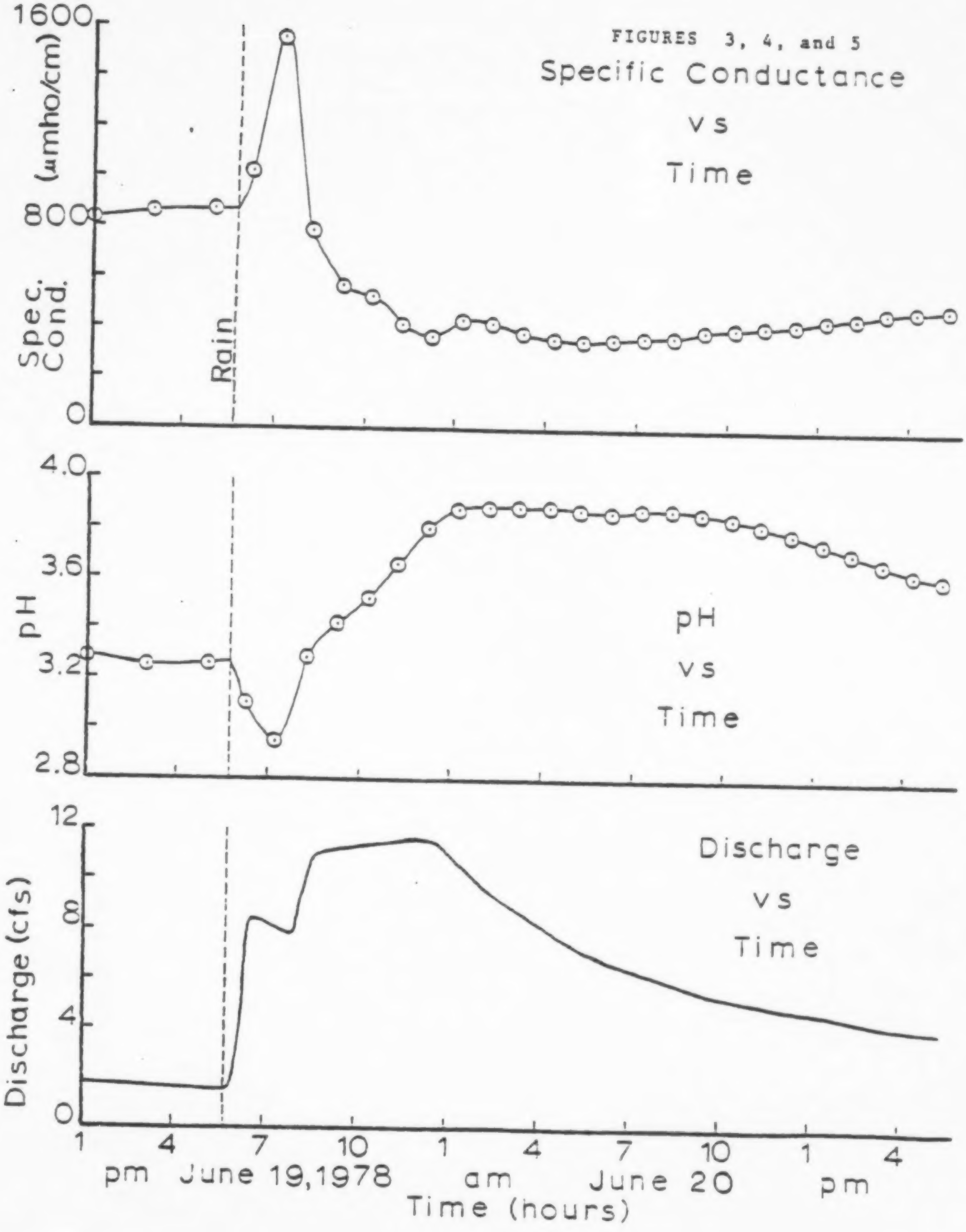
Date and Time	pH	Specific Conductance (µmhos/cm)	Gauge Height (ft)	Discharge (l/s)	Concentrations (mg/l)									
					Cu	Zn	Fe	Mn	Cd	Pb	Ca	Mg	Na	K
11:25	5.39	203	0.715	66.8	0.09	3.05	.08	1.20	0.010	<0.1	14.8	9.1	2.76	1.62
11:55	5.31	203	0.710	64.3	0.09	4.39	.09	1.20	0.010	<0.1	14.7	9.2	2.75	1.59
12:25 pm	5.26	205	0.705	62.0	0.09	2.13	.09	1.18	0.010	<0.1	14.9	9.4	2.76	1.60
12:55	5.17	207	0.700	59.5	0.09	1.99	.10	1.19	0.010	<0.1	14.8	9.4	2.75	1.62
1:55	5.15	214	0.695	57.2	0.10	2.07	.13	1.29	0.010	<0.1	15.7	9.8	2.79	1.63
2:55	5.21	223	0.690	54.9	0.10	2.07	.09	1.26	0.010	<0.1	16.3	10.1	2.86	1.62
3:55	5.21	226	0.685	52.7	0.09	2.10	.09	1.36	0.010	<0.1	16.8	10.4	2.93	1.73
4:55	5.22	235	0.675	47.9	0.10	2.13	0.15	1.47	0.010	<0.1	17.6	10.9	2.95	1.65
5:55	5.20	240	0.670	45.6	0.10	2.17	0.16	1.46	0.010	<0.1	17.6	10.9	3.00	1.66
6:55	5.18	244	0.665	43.3	0.11	2.32	0.15	1.52	0.010	<0.1	17.9	11.2	3.01	1.65
7:55	5.18	248	0.665	43.3	0.11	2.39	1.15	1.55	0.010	<0.1	18.3	11.4	3.06	1.69
8:55	5.18	249	0.660	41.1	0.11	2.38	1.15	1.54	0.010	<0.1	18.5	11.4	3.07	1.67
9:55	5.16	254	0.655	39.4	0.11	2.48	1.16	1.56	0.010	<0.1	18.0	11.4	3.06	1.64
10:55	5.13	256	0.650	37.4	0.11	2.43	1.11	1.56	0.010	<0.1	17.8	11.3	3.11	1.70
Sept. 14, 1978														
1:55	5.12	260	0.650	37.4	0.11	2.51	0.13	1.57	0.010	<0.1	19.4	12.2	3.18	1.66
4:55	5.11	269	0.645	35.4	0.11	2.60	0.16	1.64	0.010	<0.1	20.2	12.7	3.24	1.65
7:55	5.07	278	0.640	33.1	0.12	2.79	0.27	1.71	0.010	<0.1	20.6	13.0	3.31	1.67
10:55	5.04	285	0.630	29.2	0.12	2.95	0.43	1.85	0.010	<0.1	21.1	13.5	3.35	1.67
1:55 pm	5.03	293	0.625	27.5	0.12	2.83	0.50	1.88	0.010	<0.1	21.3	13.7	3.39	1.69
4:55	4.97	302	0.620	25.5	0.12	3.10	0.46	1.94	0.010	<0.1	22.2	14.2	3.43	1.71
7:55	4.92	318	0.615	23.8	0.19	3.70	0.36	2.06	0.010	<0.1	22.5	14.7	3.46	1.70
10:55	4.90	323	0.615	23.8	0.16	3.45	0.43	2.12	0.010	<0.1	23.2	15.2	3.52	1.71

Table 11. The Rainstorm of September 12, 1978, Station #4, Contrary Creek

Date and Time	pH	Specific Conductance (μmhos/cm)	Gauge Height (ft)	Discharge	Concentrations (mg/l)									
					Cu	Zn	Fe	Mn	Cd	Pb	Ca	Mg	Na	K
Sept. 12, 1978	-	-			-	-	-	-	-	-	-	-	-	-
7:00 pm	-	-	0.800	21.5	-	-	-	-	-	-	-	-	-	-
10:00	-	-	0.800	21.5	-	-	-	-	-	-	-	-	-	-
10:40	-	-	1.100	271.8	-	-	-	-	-	-	-	-	-	-
11:05	-	-	1.020	181.2	-	-	-	-	-	-	-	-	-	-
11:15	2.90	2250	1.040	203.9	16.9	69	231	4.04	0.230	< 0.1	56.0	57.5	2.45	2.29
11:50	2.98	1550	1.120	294.5	7.30	44	109	2.92	0.110	< 0.1	38.5	32.4	2.80	2.30
12:00	-	-	1.125	303.0	-	-	-	-	-	-	-	-	-	-
Sept. 13, 1978														
12:15 am	2.97	1290	1.125	303.0	4.60	20.9	71.0	2.74	0.065	< 0.1	38.0	23.8	2.86	2.29
12:20	-	-	1.125	303.0	-	-	-	-	-	< 0.1	-	-	-	-
12:45	3.15	890	1.190	390.8	2.23	11.8	27.7	1.99	0.040	< 0.1	27.4	17.5	2.82	2.46
1:00	-	-	1.245	478.6	-	-	-	-	-	-	-	-	-	-
1:15	3.43	613	1.250	487.0	1.31	7.0	17.8	2.04	0.030	< 0.1	23.3	15.0	2.86	2.39
1:40	-	-	1.255	495.5	-	-	-		-	-	-	-	-	-
1:45	3.57	511	1.265	512.5	1.14	5.4	13.2	1.85	0.030	< 0.1	21.1	13.6	2.82	2.31
2:00	-	-	1.305	580.5	-	-	-	-	-	-	-	-	-	-
2:15	3.69	439	1.305	580.5	0.74	4.9	10.5	1.53	0.025	< 0.1	18.6	12.1	2.87	2.82
2:30	-	-	1.305	580.5	-	-			-	-	-	-	-	-
2:45	3.77	489	1.275	529.5	0.94	15.5	9.2	2.10	0.050	< 0.1	23.4	15.5	2.66	2.25
3:15	3.86	557	1.230	453.1	1.25	20.7	9.2	2.36	0.070	< 0.1	32.4	17.9	2.48	2.47
3:45	3.99	457	1.200	404.9	0.96	13.8	9.4	1.80	0.050	< 0.1	25.9	13.8	2.59	2.25
4:15	3.98	355	1.170	362.5	0.61	7.4	9.2	1.55	0.030	< 0.1	17.6	10.0	2.65	1.91
4:45	3.91	313	1.145	328.5	0.44	4.5	10.1	1.28	0.010	< 0.1	13.6	8.4	2.63	1.69
5:15	3.91	298	1.130	308.5	0.39	3.3	10.5	1.18	<0.010	< 0.1	12.0	7.9	2.64	1.70
5:45	3.94	294	1.115	288.8	0.38	2.81	11.1	1.18	0.010	< 0.1	11.4	7.8	2.63	1.68
6:15	3.90	299	1.100	271.8	0.38	2.67	11.8	1.24	<0.010	< 0.1	11.3	8.0	2.64	1.66

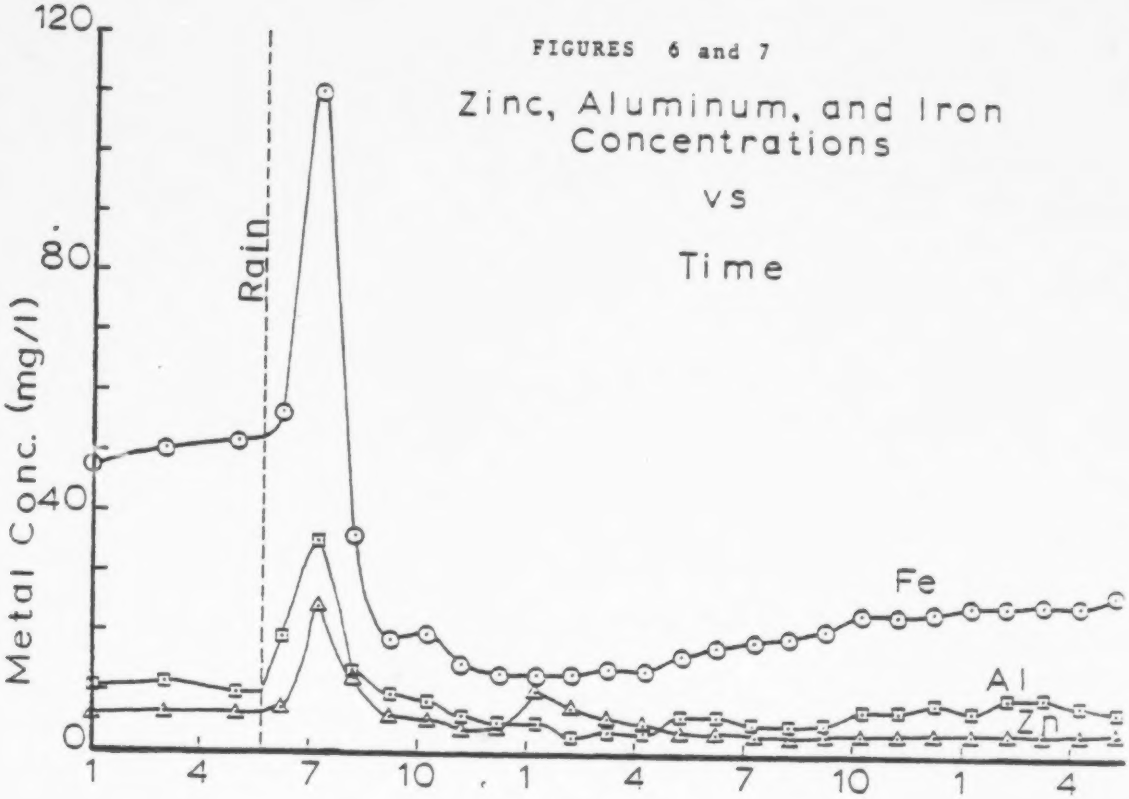
Table 11. The Rainstorm of September 12, 1978, Station #4, Contrary Creek (continued)

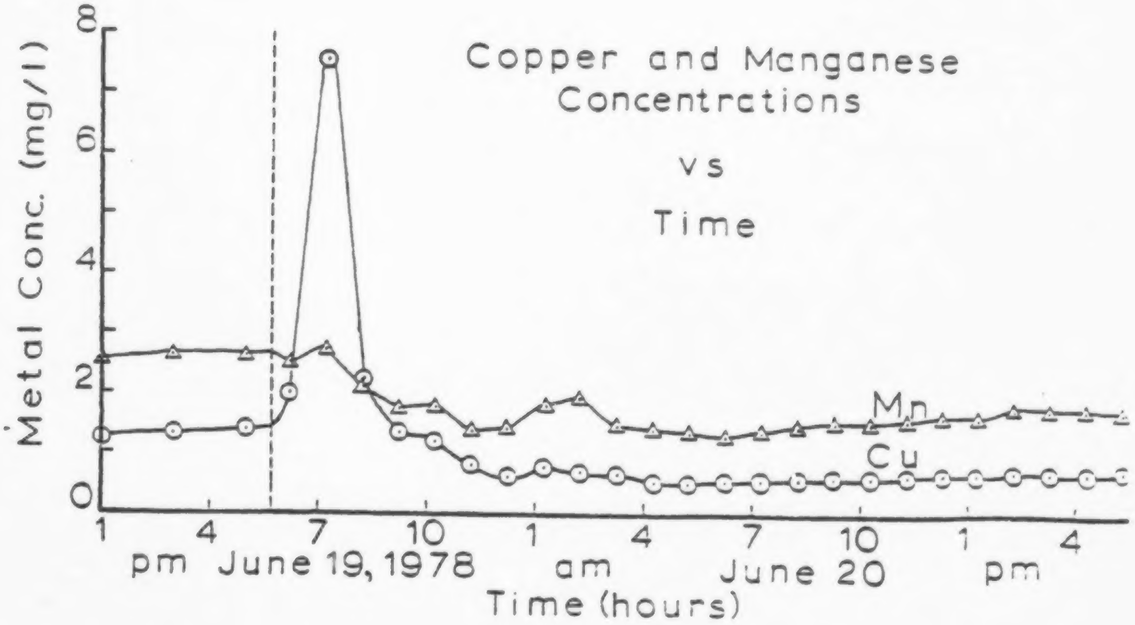
Date and Time	pH	Specific Conductance (μm /1)	Gauge Height (ft)	Discharge (1/s)	Concentrations (mg/1) Cu	Zn	Fe	Mn	Cd	Pb	Ca	Mg	Na	K
6:45	3.90	310	1.085	254.9	0.40	2.66	12.6	1.28	0.010	<0.1	11.3	8.2	2.68	2.53
7:15	3.90	310	1.075	243.5	0.40	2.68	12.8	1.30	<0.010	<0.1	11.5	8.4	2.65	1.63
7:45	3.89	317	1.065	232.2	0.42	2.70	13.4	1.29	<0.010	<0.1	11.7	8.6	2.71	1.64
8:15	3.89	324	1.050	215.2	0.42	2.65	14.4	1.30	<0.010	<0.1	11.5	8.7	2.73	1.68
8:45	3.81	331	1.040	203.9	0.44	2.80	15.1	1.29	<0.010	<0.1	12.1	9.3	2.71	1.61
9:15	3.81	350	1.030	192.6	0.47	2.86	16.0	1.31	<0.010	<0.1	12.4	9.5	2.77	2.12
9:45	3.83	346	1.020	181.2	0.46	2.88	16.7	1.31	<0.010	<0.1	12.7	9.8	2.80	1.71
10:15	3.83	351	1.010	169.9	0.47	2.91	17.0	1.31	<0.010	<0.1	12.3	10.0	2.80	1.65
10:45	3.83	357	1.000	158.6	0.51	2.91	17.5	1.30	<0.010	<0.1	12.6	10.1	2.84	1.63
11:15	3.83	363	0.990	149.8	0.52	3.01	18.3	1.30	<0.010	<0.1	12.9	10.4	2.95	1.65
11:45	3.82	377	0.985	145.3	0.53	3.09	18.9	1.33	0.010	<0.1	13.2	10.5	2.87	1.78
12:15 pm	3.79	391	0.980	140.5	0.58	3.23	20.5	1.34	0.010	<0.1	13.3	10.8	2.89	1.71
12:45	3.76	413	0.975	136.2	0.62	3.38	22.0	1.38	0.010	<0.1	13.7	11.4	2.88	1.74
1:45	3.70	438	0.975	136.2	0.65	3.62	21.1	1.41	<0.010	<0.1	14.4	11.9	2.93	1.79
2:45	3.70	441	0.970	131.7	0.65	3.72	21.3	1.45	0.010	<0.1	14.7	12.0	2.96	1.73
3:45	3.70	450	0.960	123.2	0.66	3.70	22.1	1.48	<0.010	<0.1	15.1	12.5	2.96	1.74
4:45	3.69	466	0.955	119.5	0.70	3.69	24.9	1.51	0.010	<0.1	15.6	13.0	2.97	1.69
5:45	3.68	471	0.950	115.8	0.72	3.79	26.0	1.57	<0.010	<0.1	16.0	13.5	3.04	1.75
6:45	3.68	480	0.945	111.9	0.73	3.85	26.4	1.62	0.010	<0.1	16.2	13.7	3.04	1.76
7:45	3.67	493	0.940	107.6	0.75	3.98	26.8	1.66	0.010	<0.1	16.6	14.1	3.06	1.76
8:45	3.67	502	0.935	103.6	0.76	3.97	27.7	1.68	0.010	<0.1	17.0	14.5	3.13	1.75
9:45	3.66	510	0.930	99.4	0.76	3.99	28.5	1.71	0.010	<0.1	17.0	14.6	3.15	1.75
10:45	3.66	522	0.925	95.7	0.79	4.867	29.3	1.77	0.010	<0.1	17.4	14.9	3.21	1.78
11:45	3.57	528	0.920	91.7	0.79	3.91	28.5	1.80	0.010	<0.1	17.8	15.3	2.24	1.82
Sept. 14, 1978 2:45 am	3.56	553	0.915	87.8	0.81	4.17	31.3	1.89	0.010	0.1	18.4	16.1	3.31	1.90
5:45	3.57	570	0.905	80.1	0.83	4.37	33.0	1.93	0.010	0.1	18.8	16.5	3.34	1.94
8:45	3.57	586	0.900	76.5	0.85	4.44	35.0	1.98	0.010	0.1	19.3	17.1	3.38	1.83
11:45	3.57	592	0.900	76.5	0.85	4.79	35.7	2.02	0.010	0.1	19.7	17.4	3.44	1.83
2:45 pm	3.53	663	0.890	69.4	0.89	4.87	37.9	3.07	0.010	0.1	20.1	18.2	3.44	1.82
5:45	3.50	655	0.885	66.0	0.93	5.12	38.5	2.15	0.010	0.1	20.8	18.9	3.47	1.85
8:45	3.49	674	0.880	62.6	0.97	5.13	41.0	2.20	0.010	0.1	20.9	19.4	3.55	1.86
11:45	3.50	683	0.875	59.2	1.00	5.29	43.1	2.18	0.010	0.1	21.3	20.0	3.55	1.86



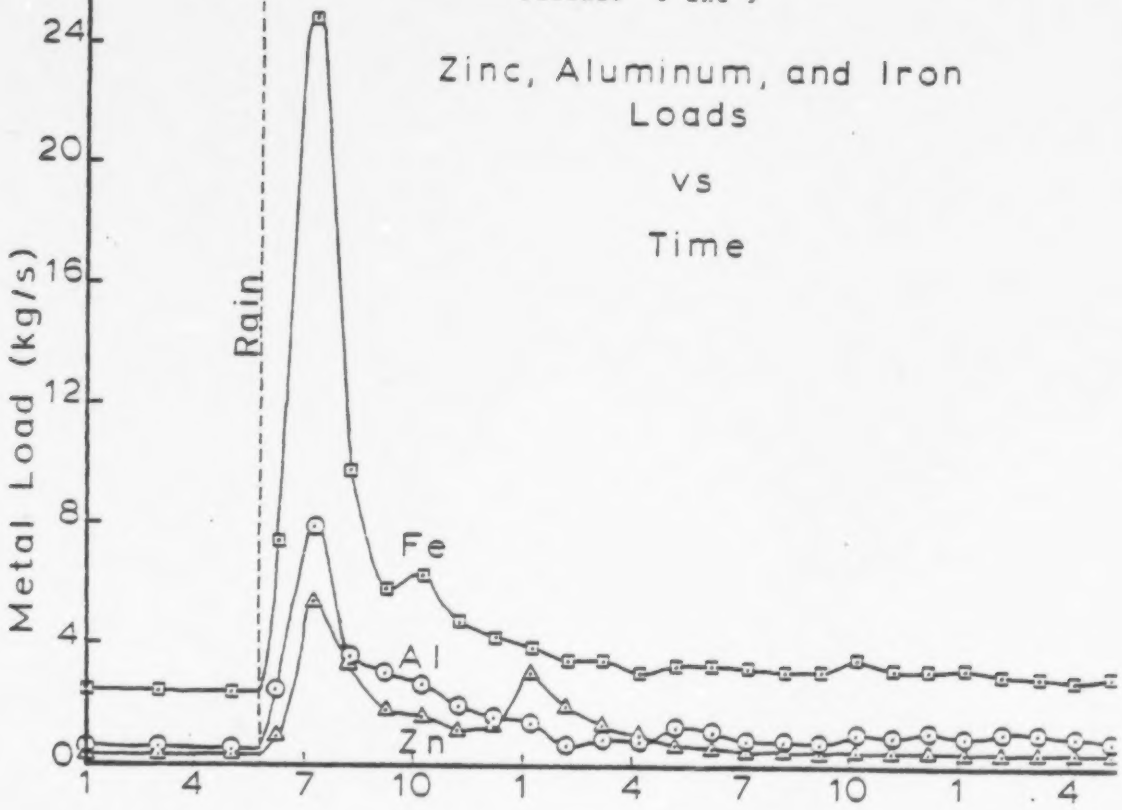
FIGURES 3, 4, and 5

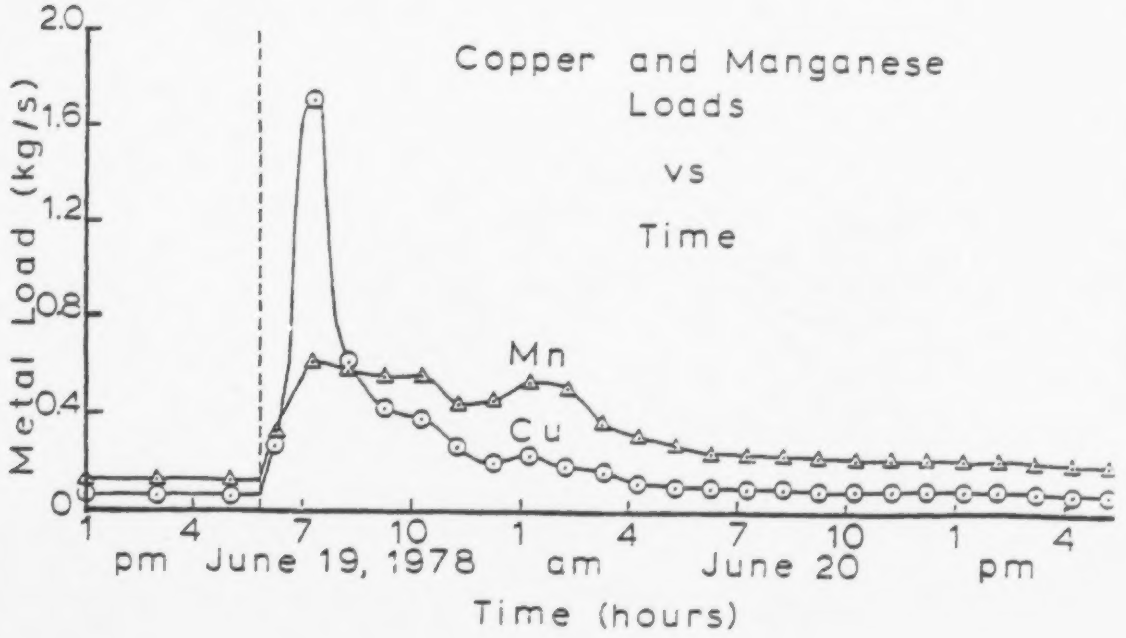
FIGURES 6 and 7


Zinc, Aluminum, and Iron Concentrations vs Time


Copper and Manganese Concentrations vs Time

FIGURES 8 and 9





All water samples were analyzed for pH, specific conductance and temperature in the field except those in Table 9 which were measured in the lab on the following day. Immediately upon returning to the lab, dissolved iron, copper, zinc, manganese and aluminum were determined by atomic absorption spectroscopy. For the first five storms the water samples were neither filtered nor acidified since it would take as long to treat the samples as it would to return to Charlottesville and run an iron analysis. There was also a critical shortage of sample bottles in which to store treated samples at that time. Samples from the sixth storm were filtered (0.45 μ filters) and acidified in the field. In addition to the metals mentioned above, the major cations and anions are being analyzed in the samples collected from the sixth storm.

For the third, fourth and fifth storms water samples remained in the automatic sampler for several days due to the length of the sample period. When the samples were picked up, it was found that oxidation of iron from the ferrous to ferric state had induced flocculation of ferric hydroxide. Consequently the dissolved iron and pH values may be useless. For these three storms the pH, specific conductance and iron values were either not measured or they should be considered as rough estimates where reported. However, the copper, zinc, manganese and aluminum values are reliable for the following reason. Flocculated samples have been analyzed for these metals both before and after acidification and results indicate that at the pH values characteristic of Contrary Creek, all of these metals remain in solution even though iron hydroxide precipitates. Therefore, values for copper, zinc, aluminum and mangenese listed in Tables 7 through 11 represent both total and dissolved concentrations. The iron concentrations listed in these tables only represent dissolved iron at the time of analysis and not at the time of sample collection. The stability of dissolved iron in samples stored in the automatic sampler determined by removing a portion of the first sample and immediately filtering and acidifying it. Iron levels in the treated sample were compared to the iron levels in the untreated sample stored in the automatic sampler overnight. A decrease of less than 5% was found in the untreated sample. If a sample was left more than 36 hours without treatment, the ice in the sampler melted and significant iron oxidation occurred as manifested by an orange gel coating the walls of the sample bottles. In summary only the first, second and sixth yielded good dissolved iron data. Total iron was not determined except on a few random samples. Total iron is about 50% greater than dissolved iron during high discharge. In the previous progress report we reported that total iron was equal or nearly equal to dissolved iron during low flow. Prior to a storm, the creek water is clear and the creek bottom gradually accumulates a thick (1-2 cm) orange carpet of amorphous ferric hydroxide. During a storm the turbulence associated with increased discharge churns up the unconsolidated ferric hydroxide thus creating a suspended iron load and coloring the creek a muddy orange. The orange carpet is noticeably thinner after a storm.

Several general trends are apparent in the chemical data for Contrary Creek during rainstorms. For the first one to two hours of a rainstorm the concentrations of iron, copper, zinc, and aluminum and the specific conductance rise abruptly with the initial increase in discharge. Simultaneously the pH falls. These data demonstrate a surge of surface runoff from the old Sulfur Mine site which is only a few hundred meters upstream of monitoring station #4., Readily soluble, efflorescent sulfate minerals supply a mobile form of heavy metals to surface runoff. Less obvious sulfate minerals impregnating the soil may actually be more important than these visible efflorescences. Dark brown pools of acid seepage laden with metals are scattered along the creek banks and these pools may also contribute to the metal loading when the turbulence of the rising waters mixes with these pools. The drop in pH concommitant with the increase in metal concentration results from (1) the hydrolysis of iron in the ferric sulfate minerals, especially copiapite, and (2) the flushing of acid from the top few centimeters of soil.

There are several reasons why the acid seep pools probably make a negligible contribution to the spike in the dissolved constituents during the first part of a rainstorm. First, the fast response time seems to indicate a readily mobilized form such as soluble salts in surface runoff. The seep pools are dense, stable layers which tend not to be mixed into the main stream until the discharge has risen considerably and become turbulent well above the water level at low flow. Second, the seep pools probably represent, at maximum, about 1% of the total volume of the water in the area of the Sulfur site. If we assume their average conductance is 25,000 micromhos and figure on a 1:100 dilution on mixing then their conductance contribution would only be an additional 250 micromhos. Since Contrary Creek varies around 300-500 micromhos at low flow then the seep pool contribution could only amount to an additional 50-80% whereas the actual increase is anywhere from two to eight times the contribution at low flow. It also might be argued that additional seepage water might be discharged into the stream during a rainstorm by elevation of the groundwater table or increased soil water flow. However, this phenomenon would be a delayed response effect which would not show up in the first hour or two of the rainstorm (especially since the tailings piles contain a lot of impermeable clays). Finally, as explained below, the relationship between the chemograph record (the spiking effect in metal concentrations), the weather patterns and the duration of dry periods can be more readily explained in terms of the dissolution of efflorescent salts than the mixing in of seepage waters.

Several factors control the magnitude of the peak metal loads and concentrations. First, the length of the dry spell preceeding the storm is important. Longer periods allow greater oxidation of the primary sulfide minerals and greater development of sulfate efflorescences. These efflorescences form by capillary upflow and evaporation of metal sulfate bearing interstitial water in the mine dump soil. Second, climatic factors such as temperature, relative humidity and wind speed are important. High temperatures, low relative humidity and high wind speeds favor evaporation which in turn encourages heavy development of sulfate efflorescences. High relative humidities and high temperatures increase the oxidation rate. Third, the amount of rainfall and its duration influence the peak magnitudes. Sufficient rain must fall to saturate the surface of the soil before there can be significant overland runoff. If the rain falls slowly over time, the metal peaks will be diffuse and weak. When the runoff is slow, much of the rainwater will infiltrate carrying the metal into the ground instead of directly to the creek.

The first storm on June 8 exemplifies the worst conditions for seeing metal concentration and load peaks, i.e., a weak storm on the day after another storm. Consequently, the peak copper and zinc loads were barely twice the baseline loads. The fifth storm on July 2 demonstrates moderate metal loading because it was a moderate intensity storm after a five day dry spell. The peak copper and zinc loads for this storm were roughly quadruple the baseline loads. The second storm on June 19 represents high metal loading because of a very heavy thundershower following six days of dry weather. As a result, peak copper and zinc loads gave more than a twenty fold increase over baseline. The sixth storm on September 12 occurred under extreme conditions. The very heavy thunderstorm of short duration was preceded by almost two weeks of hot, dry weather. The resulting peak in the copper and zinc loads was roughly fifty times the baseline loads. The third and fourth storms were sampled at such broad intervals, i.e., three hours, that discussion of the data would not provide any further information.

Once the metal concentrations and loads peak, they drop very rapidly (see Figure 3-9). This drop occurs for several reasons. The supply of soluble metal sulfates becomes exhausted and unpolluted runoff from upstream sources dilutes the Sulfur Mine runoff. In some storms the rain may stop before the efflorescent minerals completely dissolve, thus halting the transport of metals to the creek. Metal loads do not fall as rapidly as the metal concentrations because the creek discharge continues to rise while concentrations fall. In fact, the creek discharge generally reaches a broad peak several hours after the metal concentrations. Dilution causes metal concentrations to fall below normal dry weather levels. The metal loads remain substantially above fair weather loads because the discharge is high. If this were a simple system with a single mine polluting Contrary Creek, the metal concentrations and specific conductance would be expected to rise slowly to their pre-storm levels as dilution effects subside. Simultaneously pH values, discharge and metal loads would be expected to fall gradually to normal levels. Instead specific conductance and some of the metal concentrations, especially zinc, rise to a second smaller peak.

This second concentration peak arrives at monitoring station #4 anywhere from four to eleven hours after the first concentration peak. The travel time depends on the storm's intensity. Higher stream velocities which accompany the higher discharge from a sudden, heavy thunderstorm, like the September 12 storm, result in a quick arrival. Also surface runoff develops more quickly in a heavy rain so soluble sulfate minerals are transported to the creek faster. Conversely weak storms, like the July 2 rain, result in a slow arrival. The correlation of travel time with storm intensity suggests that the second concentration peak originates from a source at a constant distance upstream from the Sulfur Mine. During the last storm, water samples were collected upstream of the Sulfur Mine at monitoring station #3. These samples indicate that the second concentration peak seen at monitoring station #4 originates from the Arminius Mine based on the following line of reasoning. Monitoring station #3 is located on the downstream edge of the Boyd Smith Mine and 1.4 kilometers below the Arminius Mine. During a storm both mines would be expected to produce a metal loading peak, but the Boyd Smith peak would arrive first because of the mine's proximity to the station. Indeed two peak copper loads were measured at station #3. The first peak arrive an hour after the storm began and the second peak arrived two hours later. The Boyd Smith peak, the first to arrive, carried only one-fifth the copper load of the Arminius peak. Of the two loading peaks detected at station #3, only the Arminius peak carried enough copper to produce the second loading peak measured at station #4. Therefore, it appears that surface runoff from the Arminius Mine is responsible for the second loading peak at both stations #3 and #4. In contrast, the large first peak at station #4 comes from the Sulfur Mine and the first peak at station #3 comes from the Boyd Smith Mine. Whether the weak Boyd Smith peak can be discerned between the huge Sulfur and Arminius peaks at station #4 is questionable. Further analysis of samples from the last storm for zinc, lead, cadmium, iron, aluminum and manganese will be completed before any final conclusions are drawn. However, certain field observations also indicate that the Arminius Mine produces the second metal loading peak. First, sulfide ore and sulfate efforescences are much more abundant at the Arminius Mine than the Boyd Smith Mine. Second, the Arminius Mine tailings cover roughly twice the area of the Boyd Smith Mine tailings.

The chemical composition of the second loading peak at station #4 in the first, second, fifth and sixth serves as a fingerprint for sources of the metal. For example, the zinc to copper ratio in the second peak is roughly double the ratio in the first peak. This high ratio implies a zinc rich source for the second peak, such as the Arminius Mine which is know for its zinc rich sulfide ore. Manganese and specific conductance climb to much weaker peaks. During most storms, iron, aluminum and pH values do not reach a second peak at monitoring station #4. A second iron peak may form from the Arminius dishcarge but in the time the water takes to flow to monitoring station #4, the iron may oxidize and flocculate out. Consequently the second iron peak could be obliterated. Above the Sulfur Mine dissolved aluminium may precipitate as the hydroxide because of the high pH values associated with storm runoff and thus eliminate the second aluminum peak if it exists.

Once the second peak has passed, the creek behaves as expected. Discharge, metal loads and pH values gradually fall to dry weather levels. At the same time, metal concentrations and specific conductance rise to normal values. With the fall in discharge the orange turbidity disappears and the creek water regains its transparency. The creek chemistry requires approximately a week to return to quasi-steady conditions. Recovery time appears to vary depending upon the intensity and duration of the rain.

An example of the relative contributions of metal concentrations from the various tributaries and mine sites can be seen on Table 12. Several items are worth noting from these data. The most acid tributary is Tr-2 with the lowest pH (2.75) and the highest conductance (2788). This tributary drains from a shaft of the Sulfur Mine which is probably connected to a large excavated or caved in area just south of the shaft by underground workings. The excavated area is filled with water and probably represents the level of the ground water table. This level is several feet higher than the level of Contrary Creek, thereby exerting pressure on subsurface waters to flow towards the creek. Although Tr-2 is very acid it does not have as high metal concentrations as some of the other tributaries and it has the lowest flow. During the summer and fall it commonly dries up.

Certain variations in metal concentrations are particularly noteworthy. During downstream transport from CC-1 to CC-4 the largest increases in hydrogen, copper and iron concentrations occur between CC-3 and CC-4 (past the Sulfur Mine tailings piles). In contrast the largest increase in zinc and calcium concentrations occurs between CC-1 and CC-2 and the largest increase in manganese occurs between CC-2 and CC-3. These data implicate the Arminius site as a source of anomolously high zinc leaching and the Boyd Smith site as a source of anomolously high manganese leaching. Although the abundance of zinc and manganese-rich minerals in the respective ore deposits are not known at this time it certainly is a point worth pursuing. Boulders from the Arminius tailings have been found to contain abundant crystals of gahnite, zinc-rich spinel, and this observation may be indicative of a zinc-rich portion of the ore body.

Increases in magnesium, sodium and potassium are either proportionally about the same between monitoring stations in Contrary Creek or are negligible. These elements are indicative of leaching of the country rock, a quartz-sericite-chlorite schist, which is the same throughout all the mineral deposits and would not be expected to reflect any anomolous values in the water chemistry.

Metal loads have been calculated from the data in Table 12 to demonstrate the relative mass transport of dissolved metals from different sources (Table 13). If CC-4 is considered the point of mass output from the watershed and CC-3, Tr-1 and Tr-2 are considered identifiable overland flow inputs then the difference represents non-identifiable inputs which are primarily subsurface seepage (includes both inter-flow and base flow). On this basis we find that overland flow accounts for only 11% of the copper input at the Sulfur site and 89% comes from subsurface seeps. This amount is a very large component of subsurface flow compared to zinc which is 41% overland flow and 59% subsurface

Table 12.

Chemical Data for Contrary Creek and Tributaries on December 8, 1978*

Source	Cu	Zn	Fe	Mn	Cd	Pb	Ca	Mg	Na	K	pH	spec. cond.	Flow
TR-1	.32	2.38	29.0	0.36	0.010	<0.5	7.4	4.7	2.99	1.46	4.80	235	0.147
TR-2	4.11	6.84	63.2	8.71	0.040	<0.5	208	108	4.04	1.26	2.75	2788	0.00025
TR-4	<0.05	<0.05	0.06	0.06	0.010	<0.5	3.5	2.7	4.06	0.78	6.38	62	0.0138
TR-6	0.22	0.77	6.10	1.31	0.010	<0.5	5.9	3.6	3.75	1.20	3.55	335	0.0036
TR-7	0.20	0.82	7.15	0.41	0.015	<0.5	5.3	4.3	4.08	1.09	4.73	173	0.0203
TR-8	2.24	16.7	28.8	14.9	0.075	<0.5	49	42	4.71	5.02	3.03	1236	$\geq$0.0203
TR-9	5.73	39.8	34.0	10.0	0.300	<0.5	59	80	4.08	5.03	3.10	1702	0.00062
TR-10	0.45	17.5	0.57	17.8	0.070	<0.5	237	1[illegible]2	11.0	6.45	3.95	1962	0.0034
CC-1	<0.05	<0.05	0.27	0.04	<0.010	<0.5	3,5	2.3	3.37	1.30	6.85	59	1.90
CC-2	0.09	3.54	0.52	0.42	0.010	<0.5	12,8	7.7	3.61	1.59	5.95	184	1.67
CC-3	0.16	2.96	0.69	1.71	0.010	<0.5	19,6	13,2	3.84	1.58	4.45	299	2.45
CC-4	1.10	4.85	38.5	1.96	0.015	<0.5	18.8	17.2	3.88	1.74	3.55	597	3.80

* Concentrations are mg/l and discharges in cfs. Specific conductance is in micro Siemems/cm (equivalent to micromhos/cm).

TABLE 13. Metal Loads (kg/day) for Contrary Creek and Tributaries on December 8, 1978.

Source	Cu	Zn	Fe	Mn
Tr-1	0.11	0.86	10.5	0.13
Tr-2	0.003	0.004	0.039	0.005
Tr-4	< 0.002	< 0.002	0.002	0.002
Tr-6	0.002	0.006	0.054	0.011
Tr-7	0.010	0.040	0.355	0.021
Tr-8	≥ 0.11	≥0.83	≥1.5	≥0.74
Tr-9	0.0086	0.060	0.052	0.016
Tr-10	0.003	0.145	0.004	0.15
CC-1	< 0.23	< 0.23	1.3	0.19
CC-2	0.37	14.4	2.2	2
CC-3	0.95	17.7	4.1	10.3
CC-4	10.2	45.1	358	18.2

seepage. A similar disparity is seen for a mass balance at the Boyd Smith site where 13% of the copper is overland flow from Boyd Smith, 39% is flow from the Arminius and 48% is subsurface flow compared to 13% subsurface zinc flow. Iron behaves like copper with 96% of the input coming from subsurface seeps at the Sulfur site. Manganese is most similar to magnesium, sodium and potassium with 57% coming from overland flow and 43% from subsurface seeps. However, at the Boyd Smith site 74% of the input to CC-3 is from subsurface seeps which means that most of the manganese is coming from subsurface flow at the Boyd Smith site. Two possible reasons may explain the high manganese at Boyd Smith: (1) there may be a greater abundance of manganese in the tailings at this site or (2) a more reducing environment exists in the Boyd Smith tailings which is required for the dissolution of manganese from typical manganese-bearing minerals. The latter is the most likely of the two alternatives.

Finally, interpretations of this type (based on Table 13) are subject to criticism for several reasons and can only be considered rough estimates of a mass balance at one point in time. For example, at another time of the year the mass flow might be considerably different due to changes in the temperature, the amount of soil aeration, and the height of the groundwater table, etc. Also, chemical reactions take place, especially on mixing, which confuse these calculations. For example, iron is oxidizing and precipitating in a particulate form in the stream sediments. Trace elements are either coprecipitating or adsorbing onto sediments during transport. We have one set of data which shows a striking example of adsorption and/or coprecipitation. On August 28, 1978 samples were collected at CC-1, 2, 3 and 4 and tributaries Tr-8, 9 and 10 and analyzed for dissolved lead. Tr-8, the mouth of the main flow from Boyd Smith has the highest dissolved lead found anywhere, 0.25 mg/l (pH = 2.88). At CC-3 the dissolved lead was 0.003 mg/l (pH = 4.75), a considerable decrease for only a few meters downstream from the mixing point. Probably most of the lead was removed by sorption onto particles (or coprecipitated with ferric hydroxide) although we do not have any values for the discharge to calculate the decrease from mixing. The decrease in conductance between Tr-8 and CC-3 suggests a dilution of 4.4 times which indicates that 95% of the dissolved lead was adsorbed onto stream sediments!

DISCUSSION

The relative contribution of each of the three mines to the metal loading during storm runoff can be qualitatively evaluated with the data from the six storms. Obviously, the Sulfur Mine contributes the bulk of the metal and acidity to Contrary Creek during a rainstorm. Surface runoff from the other mines could not possibly arrive in time to add to the first and largest peak of metal concentrations and loads. For most metals it is difficult to differentiate the Arminius surface runoff load from possible Sulfur Mine interflow and baseflow loads. Zinc is an exception since it has an obvious second concentration and load peak. For the first and fifth storms the second peak zinc load approached the magnitude of the Sulfur Mine peak zinc load. However, some of the zinc loading in the creek, when the Arminius concentration and load peak arrived, was probably derived from the Sulfur Mine. The second peak zinc load during the second storm was less than half the Sulfur Mine peak load and in the sixth storm the second peak was only equal to two-thirds of the Sulfur Mine peak. Again a significant fraction of the second peak may have drained from the Sulfur Mine. Further analyses and interpretation are needed to distinguish surface runoff from base flow and interflow although the Arminius site certainly appears to be of secondary importance in zinc loading compared to the Sulfur site. Differences in rainfall intensity at the mine sites may account for some variation in the relative magnitude of peak heights. The Boyd Smith Mine has shown a small concentration and load peak at monitoring station #3 in the sixth storm. As mentioned earlier, samples were not collected for the first hour of this storm and the Boyd Smith peak seemed to be arriving when the first sample was taken. If the peak arrived earlier, then its magnitude was underestimated. However, the actual peak is not thought to have been much larger because the proximity of the sampling station to the mine indicates that roughly one hour would be required for the beginning of runoff and its flowing to the station. When this small Boyd Smith load reached monitoring station #4, it was difficult to detect because it mixed with the last part of the huge Sulfur Mine load. In Figures 6-9 for the second storm a small bulge on the shoulder of the Sulfur Mine load and concentration peaks may be the Boyd Smith load. This bulge could also represent runoff from the upper end of the Sulfur Mine, the first arrival of Sulfur Mine interflow or a second pulse of runoff from the main Sulfur Mine dumps due to a second wave of rainfall. The double peak in the discharge for this storm suggests the third alternative. Whether this bulge, or third peak, occurs during all storms is questionable. These results demonstrate the relative insignificance of the Boyd Smith Mine as a pollution source. In conclusion, the contribution by each mine to the runoff pollution is roughly proportional to the contribution by each mine during low flow conditions. Further calculations and interpretation of the data should be available in a M.S. thesis (Tom Dagenhart).

ACKNOWLEDGEMENTS

We are grateful to the Callahan Mining Corporation and Richard Kazda for allowing us to use their office shed at the Arminius Mine for shelter during field processing of samples. Also we would like to thank them for permitting access to the Cofer Mine. We are indebted to the Charlottesville office of the State Water Control Board for providing gauge height recordings of Contrary Creek and a rating curve to calculate the discharge. Both the Charlottesville office and the Bridgewater office have generously assisted in the collection of water samples and discharge data. Richard S. Mitchell of the University of Virginia first identified some of the Cofer Mine minerals. His cooperation and contribution to the study of soluble sulfate minerals at all the mines is appreciated. Pat Ryan, Andy Davis, Steve Goodwin and John Walton, graduate students at the University, have kindly assisted in the field work and in the chemical analysis.

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Appendix E

BIOLOGICAL SURVEY OF THE CONTRARY CREEK ARM OF LAKE ANNA, VIRGINIA

BS74-003

By

Richard W. Ayers
Division of Ecological Studies
Bureau of Surveillance and Field Studies

January, 1975

TABLE OF CONTENTS

Page

LIST OF TABLES 278

LIST OF FIGURES 279

ABSTRACT 280

CONCLUSIONS 281

INTRODUCTION 282

METHODS AND MATERIALS 283

RESULTS AND DISCUSSION 287
- Physical-Chemical Parameters 287
- Algae 290
  - Summary 294
- Heavy Metals 295
  - Summary 301
- Macrobenthos 302
  - Summary 305
- Fish 307
  - Summary 309

REFERENCES 310

LIST OF TABLES

Table No. Page

1 Physical-Chemical Properties at Survey Stations 288

2 Taxonomic List of Plankton Organisms per Station 291

3 Heavy Metals Analysis of Bottom Sediment 296

4 Taxonomic List of Organisms 303

5 Fish Netted in Contrary Creek 308

LIST OF FIGURES

Figure		Page
A	Map of Survey Area	286
1	Plankton Populations of the Contrary Creek Arm and Control Stations of Lake Anna, Virginia	293
2	Zinc in Bottom Sediments of Contrary Creek arm and Control Stations in Lake Anna, Virginia	298
3	Copper in Bottom Sediments of Contrary Creek arm and Control Stations in Lake Anna, Virginia	299
4	Chromium in Bottom Sediments of Contrary Creek arm and Control Stations in Lake Anna, Virginia	300

ABSTRACT

The biological conditions in the Contrary Creek arm of Lake Anna, Virginia were determined by sampling physical - chemical properties, algae, fish,macrobenthos, and bottom sediments. Acid mine drainage from the upstream, free flowing portion of Contrary Creek is causing an alteration of normal lake physical - chemical properties and algal and fish populations. The bottom sediments are contaminated with heavy metals from acid mine drainage. Macrobenthos populations are limited as much by substrate composition as by acid mine drainage.

CONCLUSIONS

1. Algal populations and light penetration data show a definite reduction in productivity in the acid waters of the Contrary Creek arm.
2. A pH and D.O gradient was noted from the upper end of the Contrary Creek arm to the control stations.
3. Heavy metals in the sediments are much higher in Contrary Creek than in areas previously unaffected by acid mine drainage and may be high enough to adversely affect macrobenthic populations.
4. Natural substrate composition in the study area is a factor favoring pollution tolerant bottom organisms, thus rendering pollution determination by evaluation of macrobenthic communities impossible.
5. The fish population of Contrary Creek has improved since creation of the impoundment.
6. This fish population is not as dense nor as diverse as that found in the main body of the lake.
7. The fish in Contrary Creek are taking up heavy metals in amounts that should require monitoring.

INTRODUCTION

During May and June, 1974, a survey was conducted on the Contrary Creek and Douglas Creek arms of Lake Anna in Louisa and Spotsylvania Counties. The purpose of the survey was to characterize the biota and the heavy metals content of the bottom sediments in Contrary Creek arm of the lake. The Douglas Creek stations were used as controls. Contrary Creek is affected by acid mine drainage from three abandoned pyrite mine sites above the lake portion of the stream.

The acid mine situation results from the oxidation of iron disulfides exposed to air by the mining activity. These materials, usually found in slag piles, when exposed to water and air are oxidized to ferrous sulfate and sulfuric acid, as in the reaction:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4$$

The ferrous sulfate is then further oxidized to ferric sulfate by chemical or bacterial activity:

$$2FeSO_4 + O + 2H_2SO_4 \longrightarrow Fe_2(SO_4)3 + H_2O + H_2SO_4(2)$$

The ferric sulfate is hydrolyzed by the water in the receiving stream to the final reaction products, sulfuric acid and ferric hydroxide.

$$Fe_2(SO_4)3 + 6\ H_2O \longrightarrow 2Fe(OH)_3 + 3H_2\ SO4\ (2)$$

The reaction products are then carried into Contrary Creek by small surface or ground water tributaries which drain the mine area. The acid water condition found upstream persists into the Contrary Creek arm of Lake Anna.

METHODS AND MATERIALS

Sediments were sampled in the former creek bottoms (maximum depth) at each station using a six-inch Ponar dredge. Material from the top 1/2 inch of the dredge sample was collected in plastic bags and refrigerated until analysis. The metals analyses were performed by the State Division of Consolidated Laboratory Services using an acid digestion-atomic absorption spectrophotometric method. Mercury digestion was done with sulfuric and nitric acids. All other metals were run using hydrochloric and nitric acids in the digestion step. The results are reported on a dry weight basis.

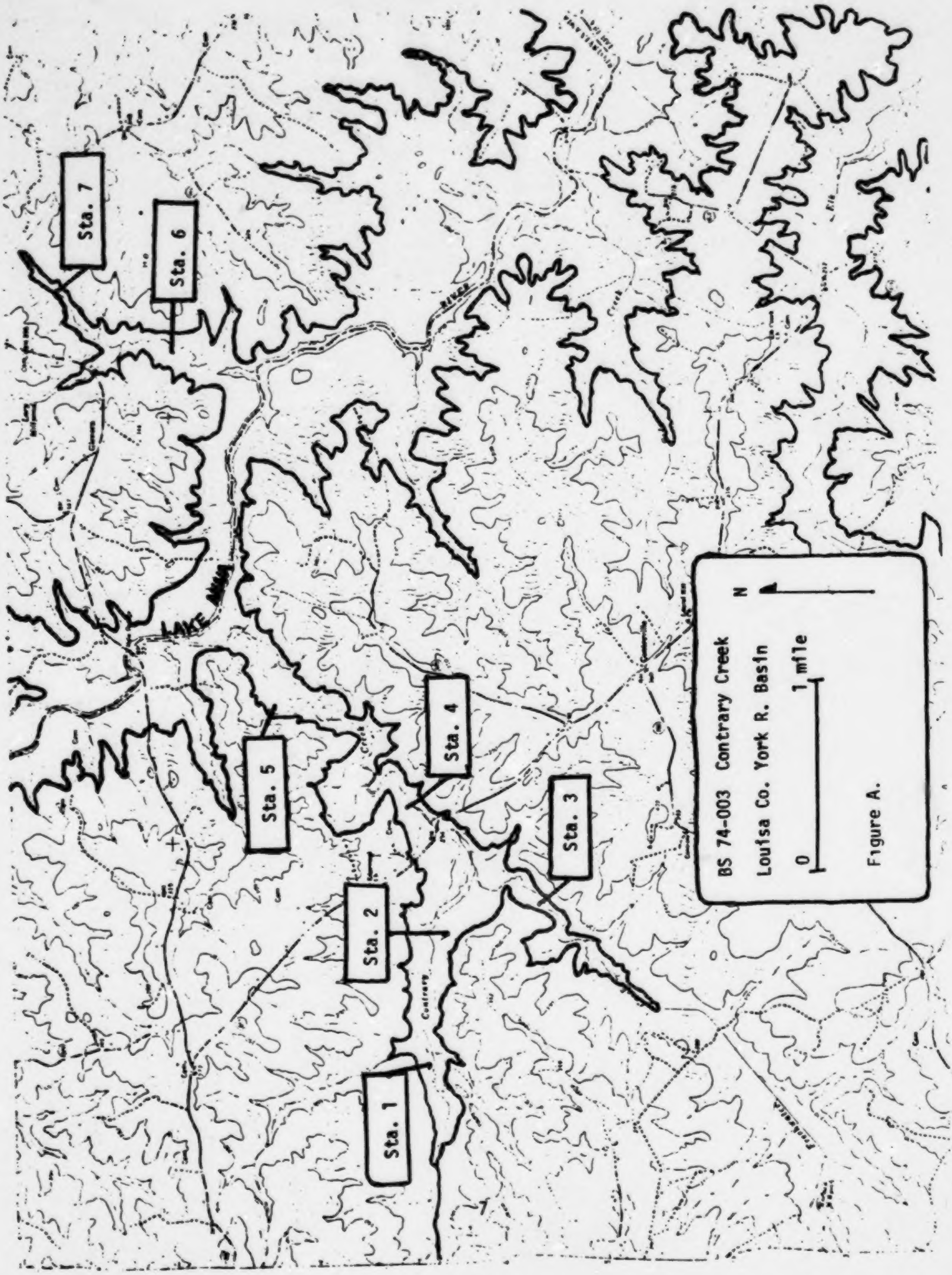
Water conditions were measured in the field with the collection of algae samples. Measurements of light penetration were made using an eight inch Secchi disc. The maximum visible depth, as the disc was lowered from the surface, was averaged with the first visible depth, as the disc was raised from the bottom, to determine light penetration. Dissolved oxygen and temperature were measured with a YSI Model 57 dissolved oxygen meter and probe. The pH was determined colorimetrically using the Hach wide range indicator kit.

Five algae samples were collected at each station. Two of the samples were surface "grab" samples. Three were collected with a Wisconsin plankton net by making vertical tows from the thermocline, when one was present, to the surface. One of the surface and two of the vertical tow samples from each station were preserved in 10% Lugols solution. The other samples were examined unpreserved. Examination of the samples was made using a compound microscope and the Palmer-Maloney Nanoplankton cell. Quantitative figures were obtained by determining the volume of water sampled by each net tow and applying this volume to the total number per milliliter figures from the Palmer cell counts.

Two grabs with a six inch Ponar dredge were taken at each station for macrobenthos identification. All benthic collections were located at approximately the same depth (four feet) to allow more direct comparison. The samples were washed in a bucket with a standard No. 30 sieve bottom. The material retained by the sieve was preserved in 70% isopropyl alcohol and returned to the office for sorting and identification. Taxonomic identification was made to the lowest level experience, available information, and time would permit.

The fish data collection and part of the interpretation for the fish section was taken from work underway by the Department of Biology, Virginia Commonwealth University under a grant from Virginia Electric Power Company. The fish were taken with experimental gill nets set over night at stations in Contrary Creek and at the reactor site. Metals analysis of fish tissue was made on an atomic absorption spectrophotometer by the flame method.

The survey area and station locations are shown on the map. Stations 1 and 2 were in the Contrary Creek arm above the confluence of Freshwater Creek. This section is the area most affected by acid mine drainage. The water is clear and live aquatic vegetation is sparse. Station 3 was on Freshwater Creek arm in an area which was not affected by acid mine drainage before the impoundment. Stations 4 and 5 were located in Contrary Creek where recovery from the upstream conditions might be expected. Station 4 was 300 yds. below the Rt. 652 bridge and Station 5 was 500 yds. above the mouth of the Contrary Creek arm. Station 6 and 7, used for unaffected comparison, were located across the lake from Station 5 in Douglas Creek. Station 7 was two thirds of a mile upstream of station 6 in a shallow tributary.



BS 74-003 Contrary Creek
Louisa Co. York R. Basin

Figure A.

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RESULTS AND DISCUSSION

Physical - Chemical Parameters

The productivity of waters is closely related to the carbonate buffering system. The addition of mineral acids, commonly found in acid mine drainage, preempts the carbonate buffering capacity, and the original biological productivity is reduced in proportion to the degree that such capacity is exhausted. Water with pH values below 4.5 is considered to be devoid of measurable carbonate buffering; and therefore, very low in biological productivity. Most researchers agree that aquatic organisms survive best in a pH range of 6.5 - 8.5 although some specially adapted forms will thrive in pH values above or below this range. In general, the density and diversity of an aquatic community will decrease when the pH falls below the optimum range.

The tests made of surface water pH indicate a definite change in water quality conditions as one approaches the main body of Lake Anna from the head of the Contrary Creek arm. The pH values from stations 1 to 4 were in the 4.0 - 6.0 range. This is below the optimum level for most aquatic inhabitants. The data for Station 5 compares favorably with pH values from stations 6 and 7. This indicates that the upper end of Contrary Creek arm is affected by low pH, while the main body of the lake is not (See Table 1).

In a study of six acid mine lakes, Smith and Frey (1970) found the level of dissolved oxygen and the percentages saturation increased with increasing pH. They found that waters with chronic low pH conditions are subject to high oxygen demand from dissolved substances and thus contain lower dissolved oxygen (DO) than waters

TABLE 1

PHYSICAL-CHEMICAL PROPERTIES AT SURVEY STATIONS

STATION	DEPTH	D.O. mg/l	TEMP.°C	pH	SECCHI DIS READING
1	Surface	6.2	23	4.0	
	3'	6.2	23	4.0	3'
2	Surface	6.9	23	4.4	
	10'		21		10'
3	Surface	7.0	23	5.3	
	10'				7'8"
4	Surface	7.5	22	5.8	
	8'		22		
	14'		19		
	16'		17		
	19'		16		
	24'		16		11'7"
5	Surface	8.0	23	7.6	
	8'	7.9	21		
	11'		20		
	15'	6.4	17		6'7"
	23'	4.6	15		
	33'	1.9	13		
	44'	1.3	13		
6	Surface	8.1	22	7.8	
	5'	8.1	22		
	10'	8.0	22		
	15'	6.2	18		6'1"
	20'	5.3	16		
	25'	4.1	14		
	36'	1.0	12		
7	Surface	8.0	24	7.7	5'2"
	6'				

without the solutes. The dissolved oxygen levels found at each of our stations indicate that no severe oxygen depletion is occurring in the acid water at stations 1-4. The DO at these stations is, however, lower than at the other stations indicating a possible correlation between low pH and lowered DO. The fact that surface temperature readings were nearly uniform for all stations also lend support to the association of pH and DO data.

A stratification of temperature and DO was noted for the deeper waters at Stations 5 and 6. No significant differences were found between the two stations in this respect and the conditions are assumed to be those normally expected in lake waters.

The penetration of light, as measured by the secchi disc readings, is much greater in the clear acid waters of Stations 1-4 than at Stations 5-7. The differences are expected as the latter stations exhibit normal pH and increased turbidity, partly due to higher concentrations of plankton. Light penetration is essential for plant growth; however, secchi readings in the Contrary Creek arm at Stations 1-4 indicate great clarity. This visibility is, unfortunately, not an indication of good growth potential but rather a lack of algal growth and natural turbidity, which would cloud the water somewhat.

Algae

A taxonomic list of plankton collected and their abundance at each station are presented in Table 2.

The majority of these algae normally exist under alkaline conditions. In areas of extreme acid conditions all organisms may be absent. Below pH 3.9 diversity is reduced to a few green algae and flagellates, both of which appeared dominant where organisms were present in Contrary Creek. Five samples were taken at each station and, while Table 2 does not show it, a small number or the absence of plankton were noted on the majority of Contrary Creek samples. This indicates a paucity of living algal species and a definite pH caused reduction in the flora of Contrary Creek. Small chlamydomonads and an unidentified oval green algae, which is probably a rarely occurring form tolerant of low pH, were the dominant species observed. Desmids, which are tolerant of low pH, were also present. These organisms were found in the very low pH waters of Contrary Creek as well as in Douglas Creek.

Asterionella, a pennate diatom capable of forming blooms, was the dominant plankton in the survey. The abundant occurrence of this organism has been reported by other workers studying phytoplankton succession in this new lake (Simmons, 1972). It is common to have a spring diatom pulse in lakes and Asterionella was undergoing such a pulse during our sampling. The population size differences in Asterionella from station to station make pH selectivity in this diatom very apparent. The Douglas Creek samples contained as much as four times as many Asterionella as the Contrary Creek samples. The Station 3 data shows a higher Asterionella population present in Freshwater Creek as well.

TABLE 2

TAXONOMIC LIST OF PLANKTON ORGANISMS PER STATION
Presented as numbers per milliliter

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Chlorophyceae							
Coelastrum						1,020	+
Pediastrum		+		1,020	1,020	1,020	
Scenedesmus				1,020		1,020	
Chlamydomonas		1,020	1,020			+	
Tetraedron		1,020					
Cosmarium						+	
Staurastrum				1,020	2,040	1,020	1,020
Mougeotia						+	
Unidentified				1,020		16,320	
Chrysophyceae							
Dinobryon							+
Centric Diatoms							
Melosira						9,640	
Unidentified							1,020
Pennate Diatoms							
Asterionella		3,060	8,160		5,100	19,380	12,240
Gomphonema							+
Tabellaria						+	+
Euglenophyta							
Trachelomonas	1,020					+	
Dinophyceae							
Peridinium				1,020			
Rhizopoda							
Difflugia				1,020		3,060	+
Rotifera							
Brachionus							+
Euchlanis							+
Filinia							+
Cladocera							
Daphnia						+	+
Copepoda			+			+	+
Total	1,020	5,100	9,180	6,120	8,160	51,480	14,280
Organisms per liter of net volume	7,698	4,730	7,884	3,156	6,839	52,875	43,363

(+)Observed

In terms of total plankton populations per milliliter of sample a definite progression can be found as one moves out of the influence of the acid mine drainage. The populations are represented graphically in Figure 1. One can see a gradual rise in over-all population from Station 1 to 5 as one moves toward the main body of the lake. The Station 3 figure is higher than any Contrary Creek sample even though it is in the Freshwater Creek arm, an area influenced by Contrary Creek water. The heavy metals content of this water may be lower than in the Contrary Creek arm and the inflow of fresh unaffected water from Freshwater Creek may be helping to maintain this higher plankton population. The control areas had from 2 (Station 7) to 6 (Station 6) times the population of the best Contrary Creek station. The difference in control figures is partly due to the difference in depth of the water at the two stations. When converted to numbers per liter of tow net volume the control stations are more closely aligned (Table 2).

The control stations, 6 and 7, show a much greater diversity of plankton than the Contrary Creek stations (Figure 1). There were 15 taxa found at Station 6 and 13 at Station 7. When these figures are compared to one for Station 1, four for Station 2, six for Station 4 and three for Station 5 the diversity differences stand out quite well. Such an increase in diversity at the controls is another indication that the conditions in the Contrary Creek arm are not suitable for abundant or normal plankton populations.

All plankton observed were typical lake inhabitants and no toxic forms were noted.

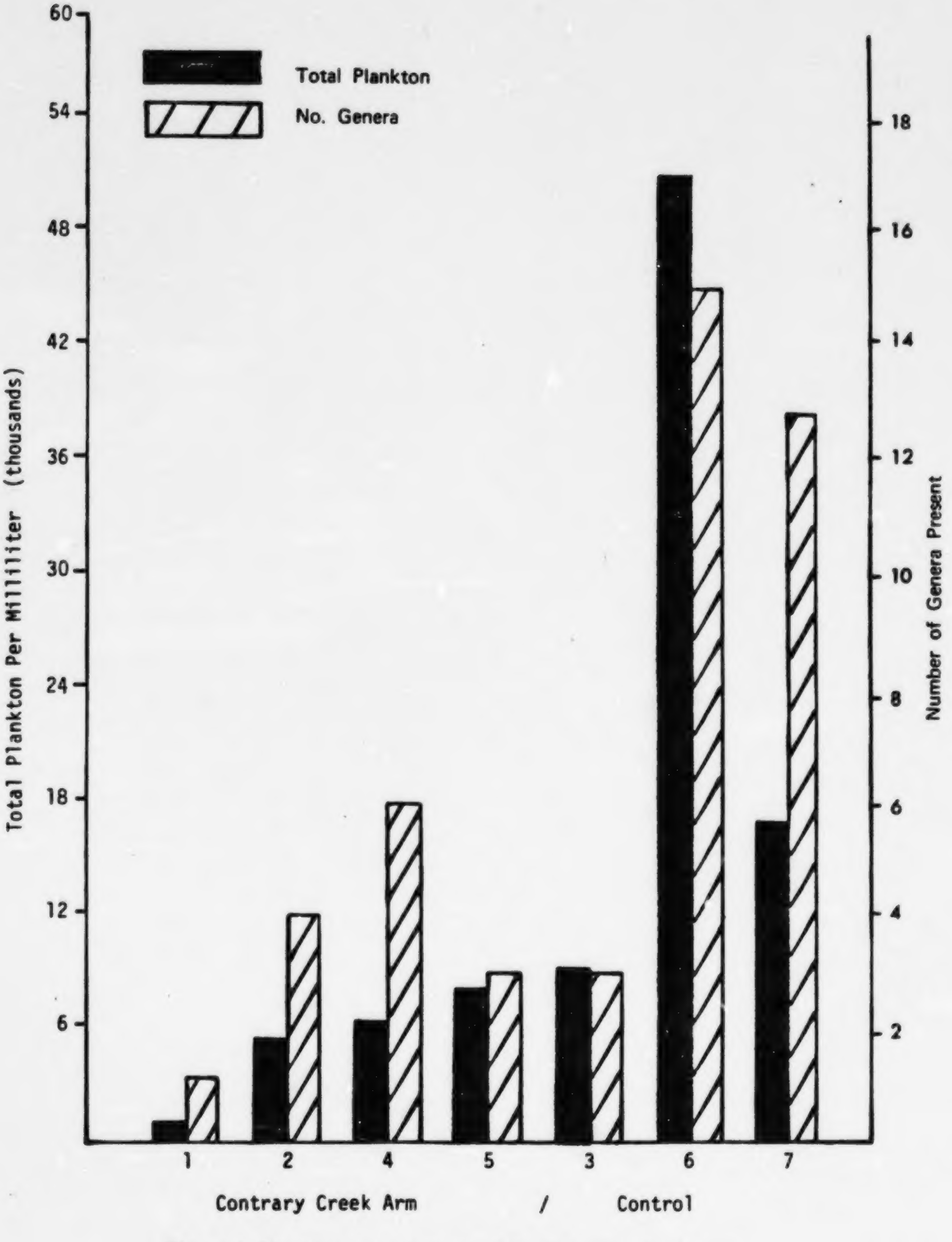

Figure 1. Plankton populations of the Contrary Creekarm and control stations of Lake Anna,Virginia.

Summary. Algae population data clearly indicates toxic conditions in the impounded sections of Contrary Creek. The plankton population of the Contrary Creek arm of the lake is depressed due to low pH conditions, which are compounded by high levels of heavy metals, low carbonate levels and low alkalinity. Pennate diatoms, green algae and flagellates are present in low numbers as compared to the population in Douglas Creek. Diversity in the Contrary Creek population is also reduced as compared to the controls.

Heavy Metals

A summary of heavy metals concentrations at the seven sampling sites is presented in Table 3.

Bottom sediments are known to concentrate heavy metals to levels many times higher than those found in the overlying water column (Benoit et. al., 1967). Metals concentrated by sediments can redissolve into the water and produce harmful effects on aquatic organisms. Figures 2, 3, and 4 indicate a high level of metals contamination in the Contrary Creek arm of Lake Anna. Stations 1, 2, 4 and 5 have consistently high concentrations of iron, lead, copper, chromium, manganese, mercury and zinc. The manganese levels did not follow the general pattern set by the six other metals tested. Iron was by far the most abundant metal followed by zinc, manganese, copper, lead, chromium and mercury.

The data indicates a trend towards heavy metals at Station 4 and 5. This might be explained by considering that metals will precipitate out of solution in higher pH water. At the same time the high levels at Station 1 and 2 may be due to settling of suspended particles carrying metals from upstream.

Due to its location on a previously unaffected stream, Station 3 sediment had low levels of heavy metals. Station 6 and 7 values were lower than the Contrary Creek stations in all but the manganese concentrations. The levels found here reflect the high metals content of the soils in the Lake Anna basin.

The levels of metals in the sediment of the Contrary Creek arm are much greater than those found in Farmville Lake, which receives

TABLE 3

Heavy Metals Analysis of Bottom Sediment
mg/kg

Station	Cu	Cr	Fe	Pb	Zn	Hg	Mn
1	799	31.9	108,000	145	1307	0.62	72.6
2	788	33.3	72,000	35	1161	0.33	131
3	80	19.4	19,000	28	320	0.05	220
4	410	35.9	610,000	296	592	0.25	137
5	904	46.0	66.000	321	1151	0.25	411
6	180	29.1	37,000	46.7	395	0.13	969
7	27.3	11.3	18,000	16.2	92	0.07	439

no acid mine drainage, following a copper sulfate caused fish kill, #74-092. The total copper values ran from 635 to 171 mg/kg in Farmville Lake while the Contrary Creek samples were in the 904 to 410 mg/kg range (Figure 3). Levels of chromium, zinc and lead were also comparable or higher in Contrary Creek.

The investigation of another copper sulfate fish kill, #69-022, on a water supply lake in Charlottesville revealed that sediment copper levels of 20 mg/kg were not harmful to bottom organisms while levels of 370 mg/kg drastically reduced the population (Figure 3).

Values of zinc, copper, chromium and lead from Contrary Creek were all at or above levels found in the bottom sediments of the Shenandoah River below Front Royal. This area has been the scene of many suspected heavy metals (zinc and copper) caused fish kills, due primarily to movement of metals stored in the sediment back into the water column. This toxicity was accomplished by the redissolving of metals during favorable water conditions and resuspension of contaminated sediment particles at other times. The spring and fall turnover activity common to lakes could make toxic levels of sediment stored heavy metals available to aquatic organisms in Contrary Creek or Lake Anna.

Bottom sediments taken following a heavy metals caused fish kill on the South Anna River in Louisa Co. (#68-060) showed chromium levels in the 27.7 to 109.2 mg/kg range (Figure 4). Zinc levels ran from 9.3 to 730.8 mg/kg (Figure 2) and lead ranged from 5.6 to 18.6 mg/kg.

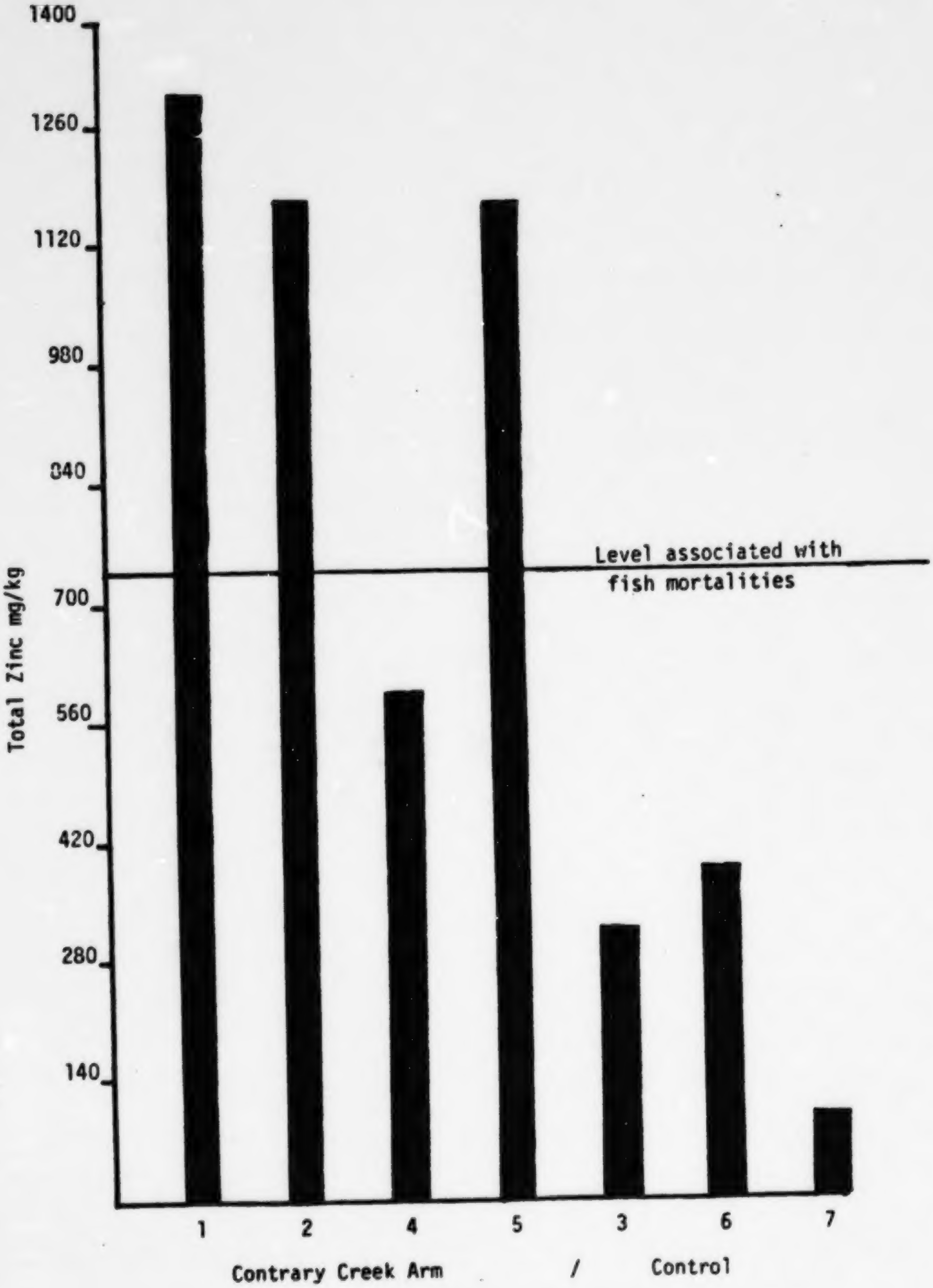

Figure 2. Zinc in bottom sediments of Contrary Creek arm and control stations in Lake Anna, Virginia.

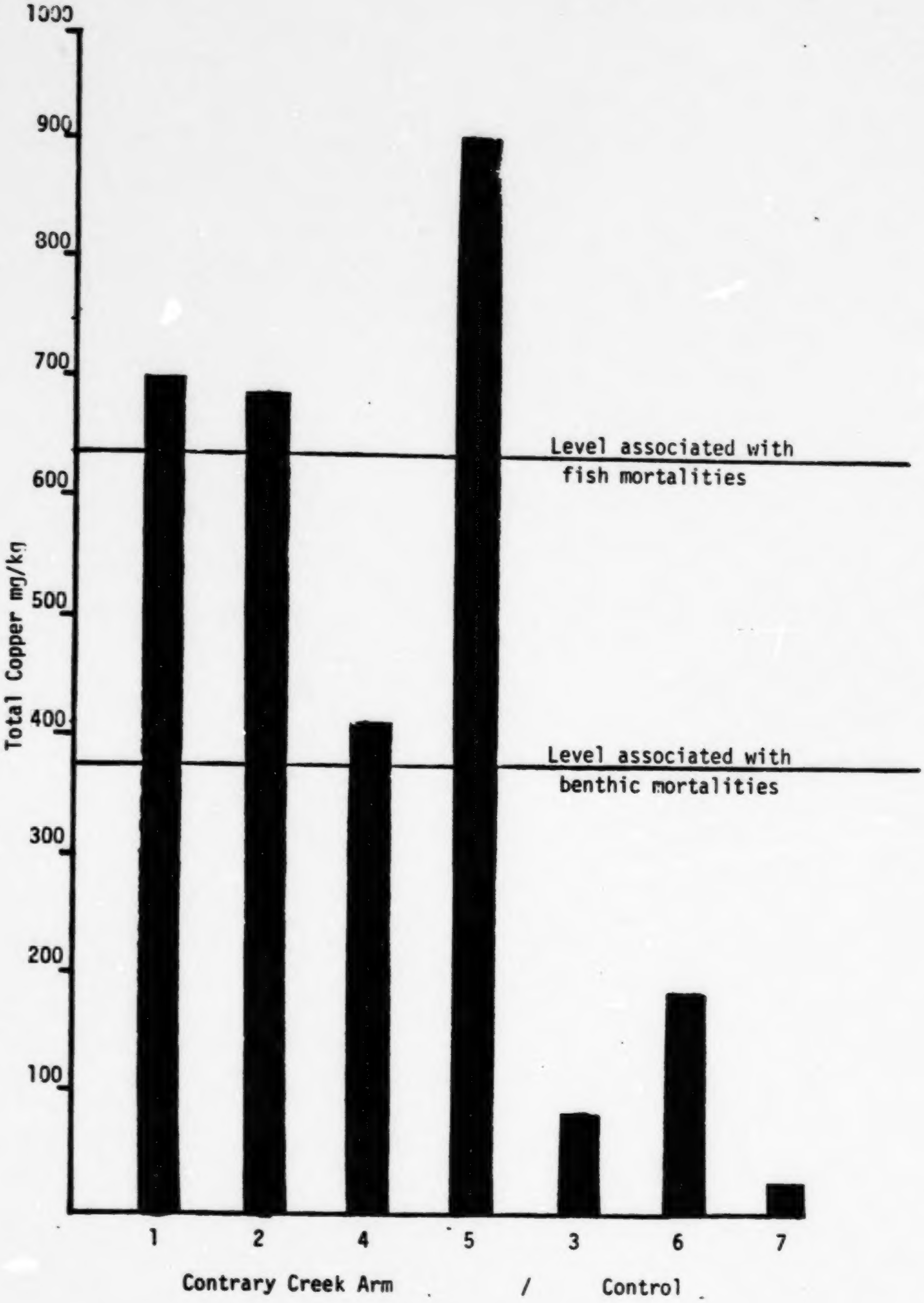

Figure 3. Copper in bottom sediments of Contrary Creek arm and control stations in Lake Anna, Virginia.

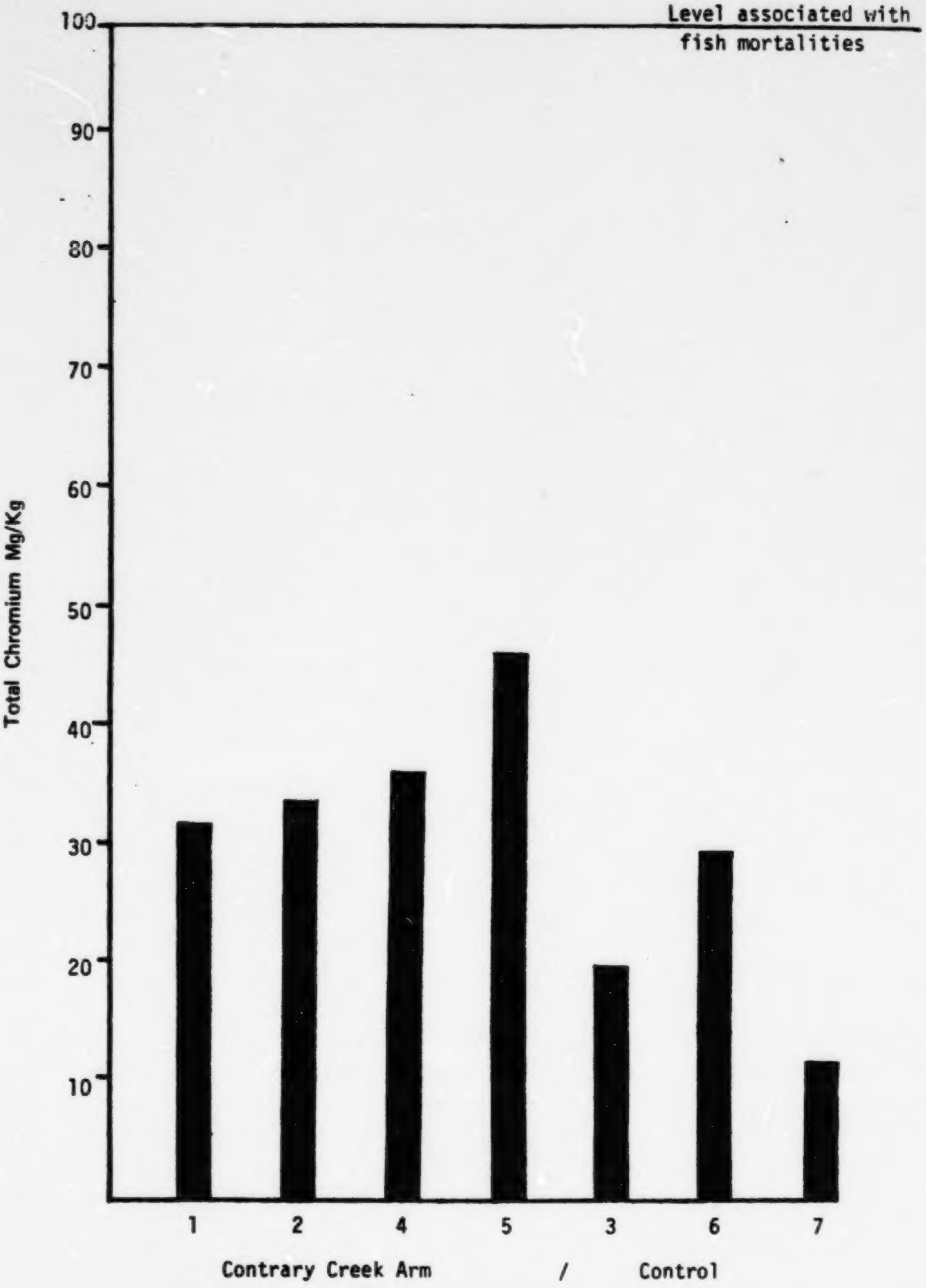

Figure 4. Chromium in bottom sediments of Contrary Creek arm and control stations in Lake Anna, Virginia.

Summary. Contrary Creek bottom sediments are contaminated with heavy metals at abnormally high levels. These levels compare favorably to those found in areas experiencing heavy metals caused fish kills. The possibility exists that these heavy metals levels could be limiting benthic populations. It is also possible that spring and fall turnover could create toxic conditions in the Contrary Creek arm of the lake by resuspending or redissolving heavy metals found in the sediments.

Note: The horizontal lines shown on Figures 2, 3, and 4 are intended to present an indication of warning level only. Other water characteristics such as pH, dissolved oxygen, suspended solids, alkalinity and hardness will affect the availability of these metals for reactions with aquatic organisms. These characteristics will vary from stream to stream thus making the indicated levels less definite for Contrary Creek but none the less useful as indicators of possible problems.

Macrobenthos

A taxonomic list of organisms is given in Table 4.

Station 1 was located just at the point where Contrary Creek becomes an arm of Lake Anna. The substrate here was mud and orange ferric hydroxide precipitate. The area is obviously subject to frequent silt deposits from the flowing portion of the stream and along with the low pH conditions, this restricts the benthic community to those forms hearty enough to survive. At this station the dominant organism was the midge Chironomus (Chironomus) sp. a very tolerant type bottom dweller. The plecopteran and the elmid beetle larva may have drifted down from upstream, their capacity to survive in conditions like those at Station 1 being very limited.

Station 2 was by far the most productive station in terms of individual organisms present. The substrate at Station 2 was dead grasses and ferric hydroxide precipitate over gravel and clay. The presence of the dead grass must constitute a much more suitable habitat than the other types of substrate found. Although midges were dominant at this station, other dipterans (insect larvae) and a few odonatans (dragonfly and damselfly) were also present. These organisms are not common inhabitants of acid mine streams but they are typical lake inhabitants. The larval and adult stages of Dineutus (whirligig beetle), were both noted at this station.

It would be difficult to say that Station 2 benthic data indicates an increase in water quality over Station 1, especially in the light of the DO and pH readings. The major factor here must be the change in substrate composition.

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TABLE 4. TAXONOMIC LIST OF ORGANISMS +

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Trichoptera							
Wormaldia				2			
Neotrichia						2	
Plecoptera							
Larva case	2						
Coleoptera							
Elmidae	2						
Dineutus	2	6		4			
Odonata							
Libellula Needhami			2				
Celithemis elisa		2					
Ischnura		4					
Perithemis tenera					4		
Libellula luctuosa		6	4				
Amphipoda							
Gammaridae						2	
Diptera							
Family Chironomidae							
Chironomus (Chironomus)	132	104	248		6	12	
Chironomus (Cryptochironomus)		4	10	4		8	2
Polypedilum		486	4	2		2	18
Paralauter borniella		2				4	
Stenochironomus						4	
Tribe Chironomini unidentified		40					
Procladius		12	12	18	16	62	80
Tanytarsus	14	440	20	8		6	12
Pupal Chironomini	10	40	4			2	
Pupal Tanytarsini		16					
Pupal orthocladinae							4
Unidentified chironomidae		54		2	4	2	
Family Culcidae							
Chaoporus		2					
Family Heleidae							
Bezzia - type larvae	2	2	—	—	4	—	—
TOTALS Individuals	164	1188	304	40	30	110	116
Taxa	7	16	8	7	4	11	5

+ Numbers are per square foot

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Weight gm/Ft^2	0.0844	0.4358	1.0458	0.0338	0.0452	0.0314	0.0140

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Station 3 was located in the Freshwater Creek arm 300 yards above its confluence with the Contrary Creek arm. This stream was not subject to acid mine waters until the impoundment activity caused the waters of Contrary Creek to mix back up Freshwater Creek. The substrate at this station was detritus over fine gravel with a thin mud layer between. No ferric hydroxide precipitate was present. The benthics here did not present what was expected, i.e,, a recovery from conditions found at the previous stations. Instead, there were fewer taxa and a lower density than at Station 2. With water quality slightly above the Station 2 levels, an explanation of this low population condition is substrate composition. The number of taxa found here was exceeded only at Station 2 and 6 and Station 3 ranked second in numbers of individuals. This indicates that the potential for population growth is good in this area but some factor, perhaps substrate, prevented us from finding what was expected.

Station 4 and 5 were on the Contrary Creek arm of the lake 1 1/2 and 1/2 mile respectively, from the confluence with the main body. The substrate conditions found at this station were similar. Both had detritus over thin mud over sand. This substrate did not prove to be attractive to large numbers of organisms. The samples were dominated by chronomid midge larvae with one or two other taxa present, all in very low density.

Station 6 was on the Douglas Creek arm about one half mile above the main body of the lake. The substrate conditions here were similar to those at Station 4 and 5 with detritus over thin mud over sand. The benthic population at Station 6 was again dominated by chironomid larvae and the diversity was second only to Station 2. Density, however, was the third lowest of all stations. Substrate composition may again be the influencing factor in benthic population. The high diversity of this station shows a potential for further growth in population size.

Station 7 was located at the upper end of the Sturgeon Creek arm of the lake. The substrate here was detritus over thick mud. This substrate is generally more hospitable to benthic colonizers than that found at Station 6. The organisms at Station 7 were all chironomid larvae with only 5 different taxa observed. The density of the population was the fourth highest of the samples collected and considering the population composition and the substrate available this density is below expectations.

Summary. The benthic populations sampled were generally low in diversity and density. All samples were dominated by the larvae of chironomid midges. While no one type was found at each station several were widespread throughout the survey area. These organisms are very tolerant and they are commonly the dominant species in acid mine drainage streams. In lakes the normal water quality may be high enough to support less tolerant forms, but factors such as substrate composition and stratification of lake water amy select the more tolerant organisms. An attempt was made to eliminate the effects of variance in water quality according to depth by sampling all stations at approximately the same depth. The selectivity of substrate for more tolerant forms may have had an important impact on the results from these samples.

The substrate at most stations was composed of a thin layer of detritus and mud over fine gravel or sand. This is not suitable for most aquatic invertebrates in terms of food sources or living habitat. The area of Station 2, which is severely affected by acid mine drainage, was more hospitable to invertebrates because of the presence of dead grasses on the substrate. The populations at Stations 3 and 6, although limited in size by the substrate, were high in diversity and indicate the potential for future expansion if the substrate conditions improve.

With the possible exception of Stations 1 and 7, the substrate sampled was not under water before the impoundment of the lake in 1972. This factor will have a great deal to do with the benthic population found at each station. The build-up of silt and organic particles with time will provide more habitat and food for benthic organisms at this depth and colonization from feeder streams and other waters should increase both density and diversity.

In terms of the effects of acid mine pollution on the bottom organisms of the Contrary Creek arm, the populations sampled did not indicate a recovery from low pH toxicity as one moved into water of more normal pH levels. In other words no pH toxicity was apparent in the benthic populations, either because it did not exist or because it was masked by a selectivity for tolerant forms on the part of the substrate.

Fish

The effects of acid mine drainage on fish populations has been widely studied. Most observers agree that pH values above 4.0 rarely prove lethal unless the lowered pH has caused the toxicity of some other water characteristics to increase. pH affects many water components, CO_2, alkalinity, and the solubility of heavy metals especially. The effects of pH in the range 4.0 - 6.6 are usually physiological and can be manifested by abnormal behavior patterns, body deformities, reduced egg production and hatchability. Mount (1973) stated that his experimental results using the fathead minnow "collectively support the need to maintain pH at or above 6.5. Even though sustained fish populations may exist at lower pH levels, production will most likely be reduced".

Eleven fish species have been collected from Contrary Creek in the area of Station 4 over the two years since 1972. See Table 5. Six of these species were not found until this year. A small population contributed to the early colonizers of Contrary Creek and the lake proper has added more species recently.

The numbers of individuals collected in the Contrary Creek arm were generally lower than those from the main body. A few species noted for the lake are not yet known in the Contrary Creek are. These may be types which are more sensitive to acid mine drainage than those found in Contrary Creek. The black crappie, golden shiner, and brown bullhead are the major species in the population of Contrary Creek. The bullhead is considered one of the species most tolerant of acid mine drainage. The abundance of crappie and shiners may be due to their early migration from Freshwater Creek. No data is available on the fish populations

TABLE 5

FISH NETTED IN CONTRARY CREEK

Esox niger	chain pickeral
Cyprinus carpio	european carp
Notemigonus crysoleucas	golden shiner
Erimyzon oblongus	creek chubsucker
Ictalurus nebulosus	brown bullhead
Lepomis macrochirous	bluegill
Micropterus salmoides	largemouth bass
Pomoxis nigromaculatus	black crappie
Perca flavescens	yellow perch
Dorosoma cepedianum	threadfin shad
*Semotilus corporalis**	fallfish

* In Freshwater Creek arm

in the area of Stations 1 and 2 but a decline from the figures from the Station 4 area would be expected. The pH change from Station 4 to Station 2, 5.8 to 4.4, is a major factor in making this assumption.

The uptake of heavy metals by fish in Contrary Creek is just beginning to attract the attention of researchers. The few creek chubsuckers analyzed for zinc and lead contamination thus far have contained levels well above those found by researchers in Illinois and Michigan who made extensive surveys of metals in fish in their areas. Although no conclusions can be made from the Contrary Creek fish data because of small sample numbers, it does indicate that the fish in the Contrary Creek arm are absorbing and storing heavy metals. The importance of this contamination from both human health and fisheries management viewpoints warrents continued intensive monitoring of fish from Contrary Creek and adjacent waters.

Summary. The fish population of the Contrary Creek arm of the lake is smaller in size and diversity than the population of the reactor site area. The Contrary Creek population is dominated by black crappie, brown bullhead, and golden shiner. Initial data on heavy metals uptake in Lake Anna fish indicates significant contamination by zinc and lead and points out the need for more research in this area.

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Appendix F

EXPERIMENTAL STUDIES AT ARMINIUS TAILINGS

BY

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NOVEMBER 1979

In 1974 and 1975 three separate sets of field revegetation experiments were established on the Arminius tailings, adjacent to and on the east side of Contrary Creek. The purpose of each set of experiments was to determine (a) species and varieties of grasses and legumes which could be successful, (b) quantities of limestone which would be appropriate for vegetation on the pyritic tailings, (c) quantities of inorganic fertilizers which would be needed, and (d) alternative soil amendments to the tailings which would act as physical conditioners and which would contribute some nutrients for vegetation.

These sets of experiments have been left in place, without any subsequent maintenance, fertilization, or other treatment since the original seedbed preparation. They have served, along with additional subsequent experiments, as a basic guide for large-scale techniques and materials for revegetation at the site of Arminius tailings on both the eastern and western sides of Contrary Creek.

These experiments also are useful in assessing the long-range prospects and maintenance requirements of the large-scale revegetation at all Contrary Creek sites since they were planted on sites which are reasonably representative of most tailings areas, and since they were initiated between one and three years earlier than other sites at Arminius, Boyd Smith and Sulfur tailings.

STUDY I: TAILINGS-ONLY EXPERIMENTS

On September 12, 1974, a randomized-block-factorial experiment was planted. There are 54 individual rectangular plots, each 7.5 feet by 6.0 feet. Nine species of grass and legumes are represented, measured against three levels of application of ground dolomitic limestone. There are two replications of each combination of vegetation species with given lime rates. A uniform rate of application of commercial fertilizer was applied just prior to planting over the entire experimental site: 10-10-10 at 1450 lb./acre.

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Grass and legume species sown by hand were:

1. Golden millet
2. Blackwell switchgrass
3. Weeping lovegrass
4. Crown vetch 'Penngift'
5. Orchard grass
6. Sericea lespedeza
7. Tall fescue 'Alta'
8. Annual ryegrass
9. Red top

Liming rates were:

1. 5.0 tons/acre
2. 2.5 tons/acre
3. No ground dolomitic limestone

Experimental preparation methods are summarized as follows:

A. Rototill site to a 6-inch depth
B. Apply fertilizer by cyclone seeder
C. Apply limestone at appropriate rates
D. Rototill entire area for the second time
E. Rake area to smooth the seedbed
F. Apply seed by hand, one variety of seed to each individual plot
G. Rake each plot to cover seed
H. Apply straw mulch to all plots, two tons per acre
I. Apply biodegradable erosion control netting to all plots

Prior to application of limestone, pH of these (as well as most Arminius tailings) was 3.6. For as long as one-and-a-half years after application, the "high" level of lime maintained pH 4.7, and the "low" rate of lime elevated it to pH 4.1.

Where lime was applied at both the "high" and "low" rates, the grasses Tall fescue, Orchard grass, Red top, and Weeping lovegrass all showed good cover and growth through the first year. During the second year (1976), marked deterioration, as evidenced by lack of vigor and dying out, occurred, especially where the "low" rate of lime had been applied. By 1977 and 1978 only very limited stands of these grasses continued to survive. This continues to be the case. On unlimed trials, only Weeping lovegrass germinated, and only in very limited numbers. A few plants still remain after five years.

Planted legumes, Crown vetch and Sericea lespedeza, germinated only where limed at "low" and "high" rates. By the fall of 1979, five years after planting, Crown vetch survives where the "high" rate of lime was applied, but there is little evidence of its spreading. Sericea lespedeza, however, has spread (by reseeding) into several other plots where limed at the "high" rate. Sericea is stunted, but continues to survive and spread at a very gradual rate.

The most successful vegetation in this experiment is one that was not sown or planted: Virginia pine. Prior to initiating reclamation experiments it was noted that in the spring, hundreds of pine seedlings had germinated at Arminius tailings on both sides of Contrary Creek, but by mid-summer these seedlings had perished. It can be assumed that this was an annual cycle which had been repeated for many years. By May, 1976, eight seedlings in the experimental plots were noted to have survived one winter. By December, 1976, 21 volunteers were noted to have survived one or more growing seasons. By 1979, the number of Virginia pines has grown to more than 100, and the tallest of these are almost five feet tall. This quantity of trees points to a potentially very dense forest growth in the future, should the trend continue. As of this time there is an average of one Virginia pine per 25 square feet in the experimental area.

It is clear that the combination of mulch, lime, and some grass growth, and to a lesser extent, fertilizer, all contributed to the proliferation of surviving pine trees. It is believed that shielding young seedlings from isolation (by mulch, and by thin stands of grass) have been the most important factors in this process. There are more trees where lime was applied at both "low" and "high" rates, but some occur in the unlimed tailings. Fertilizer does not seem to be a significant ingredient because any benefits conferred in 1974 can be assumed to have been dissipated.

In the future, it can be assumed that the invasion of pine seedlings will decelerate since very little mulch or grass still exists in quantities needed to provide the shade required on the dark-colored tailings and to prevent girdling of roots. In fact, there are very few new seedlings in 1979 as compared with 1978. By the same token, however, it can be assumed with some certainty that established volunteers will continue to grow without additional fertilizer, just as they have in the past. These, in turn, will provide greater shade as they grow. They will likely provide a more hospitable environment for future seedlings from surrounding areas. They will also provide some mulch from dropping needles and may in time produce their own seeds.

In summary, the long-term prospects for this experimental site appear to be that it will become densely covered with Virginia pines, with possibly an increase in spread of lespedeza.

STUDY II: SAPROLITE/TAILINGS EXPERIMENTS

On October 2, 1974, a block-factorial experiment was planted, with a total of 22 individual plots, each measuring 7.5 feet by 6.0 feet. The entire area was covered by approximately eight inches of saprolite. 11 plots were limed (ground dolomitic limestone at the rate of 2.0 tons per acre) and 11 were not limed. There are two replications of each of the following species and combinations, one of which was limed and one of which was not:

1. Blackwell switchgrass
2. Weeping lovegrass
3. Crown vetch 'Penngift'
4. Orchard grass

5. Sericea lespedeza
6. Tall fescue 'Alta'
7. Annual ryegrass
8. Red top
9. Red fescue 'Pennlawn'
10. Mixture of 1-4 above
11. Mixture of 6-10 above

Procedures were the same as listed above for Study I, with the following noteworthy distinctions: (a) tailings not mixed with saprolite since the coverage of saprolite was deeper than the tilling; (b) mulch applied at 1.5 tons per acre rate instead of 2.0 tons per acre.

Fertilizer (10-10-10) was applied to all areas at the rate of 1450 lb. per acre.

By May, 1976, the most promising species in terms of ground cover, were 'Pennlawn" Red fescue, 'Alta'Tall fescue, Orchard grass, and Red top. However, these lost vigor during the second growing season (1976).

Meanwhile, during this second year, both Crown vetch and Sericea lespedeza began to show signs of vigor and increased ground coverage. Photographs from 1976 show that Crown vetch was thriving only where limed, but that Sericea lespedeza was prospering both with and without lime.

As of the autumn 1979, lespedeza has spread not only into all 22 individual trials but has also reseeded outside of the boundaries of the experiment. Crown vetch continues to survive where it was originally planted, but in 1979 it began to be crowded out by lespedeza. There is little survival of Crown vetch where it was not treated with dolomitic limestone.

The spread of lespedeza has been especially marked during 1978 and 1979. This has occurred by means of reseeding, and it is anticipated that by 1980 the entire area will show an extremely dense stand of Sericea lespedeza that is about four feet tall.

Where lespedeza has been slower to invade (a function of physical distance), Virginia pines have also invaded in substantial numbers. It is uncertain at this time whether the complete, dense cover of lespedeza will crowd out the pine seedlings in this study area, but it appears likely to because of its aggressive nature.

In summary, this study area exhibits very complete coverage and extensive spreading by Sericea lespedeza, and more complete ground cover in each succeeding year.

STUDY III: SLUDGE/TAILINGS EXPERIMENTS

On October 11, 1975, six species of grasses and legumes were sown in 20 individual plots, each measuring 7.5 feet by 6.0 feet. The entire area was covered by four inches of Richmond (VA) digested sewage sludge, which was rototilled to a depth of eight inches. (Thus the top eight inches of "soil material" consisted of 50% Richmond sludge and 50% tailings, overlying Arminius tailings.)

Ground agricultural limestone was applied to the entire area at the rate of three tons per acre, and rototilled into the sludge/tailings regime. No fertilizer was applied, and no mulch or erosion control netting was used. Otherwise, procedures in Studies I and II were followed.

In the 30 individual plots, there were five (randomized-block-factorial) replications each of the following six species:

1. Tall fescue 'Kentucky-31'
2. Crown vetch 'Penngift'
3. Orchard grass
4. Ladino clover
5. Red top
6. Weeping lovegrass

The application of sludge and limestone raised initial pH of tailings (pH 3.6) to slightly higher than pH 6.0, at which point it has remained constant to date.

Early results (May, 1976) reflected the fast, aggressive growth of Tall fescue, Orchard grass, and Ladino clover.

By the end of the first growing season (1976), it was apparent that digested sewage sludge was the amendment of choice, with results far surpassing earlier experiments at the same stage of growth. By this time, however, clover had been so heavily browsed by deer as to be completely eradicated. All other species had achieved complete, vigorous, and dense ground cover.

By the spring of 1979, however, Crown vetch had become so aggressive as to invade 18 of the 30 individual trials. By October 1979, 25 of the 30 plots exhibited very dense Crown vetch, to the point that other species were crowded out.

With Crown vetch so abundant and aggressive, it can be assumed with certainty that Crown vetch will completely over-run all other species by 1980 in this experiment, because of its luxuriant growth. There is 100% lush ground cover on all plots, with either the originally planted grass or with Crown vetch. A substantial amount of organic material has been generated over this entire area during the four years since planting.

SUMMARY

By the end of the 1979 growing season, Studies I and II, and Study III have been through five, and four years', observations respectively. These five years have supplied an abundance of unusually harsh weather, ranging from extremely cold winters with abundant snow insulation, to extremely cold winters without significant snow cover, dry and wet springs and autumns, and extremely hot summers with little precipitation.

Despite all these vagaries of climate (which seem to average out to near the normal) results of each study have continued to show improving results in terms of vegetative ground cover and growth.

None of the study areas has received any maintenance at all. Yet, each of the studies shows a trend toward vegetative development in a somewhat different direction. With no amendments (i.e. using the tailings as seedbed with only short-term lime, mulch, and fertilizer) native Virginia pine is becoming well established. With saprolite, Sericea lespedeza is very aggressive and dominant. Where sludge was utilized, Crown vetch is destined to crowd out all other vegetation in the immediate future.

From these differing results, what is one to conclude from these results? At this time it seems evident that Virginia pine, native to the area, is the most tolerant species under very low-nutrient levels, and once some ground cover can be established, these will volunteer, survive and grow. This would eventually, should present trends continue, bring Arminius tailings into a general homeostasis with its surroundings from the vegetational standpoint. However, if nutritional levels and acidity are reduced near the surface by means of coverage by local red-clay subsoil (saprolite), Sericea lespedeza is likely to predominate at least for the short-run. If nutritional levels and pH are raised substantially by sewage sludge applications, growing conditions may be improved to the point that Crown vetch will not only survive but will aggressively prosper.

In each of these cases, the studies show that under representative tailings conditions at Contrary Creek, vegetation can be established and self-maintaining.